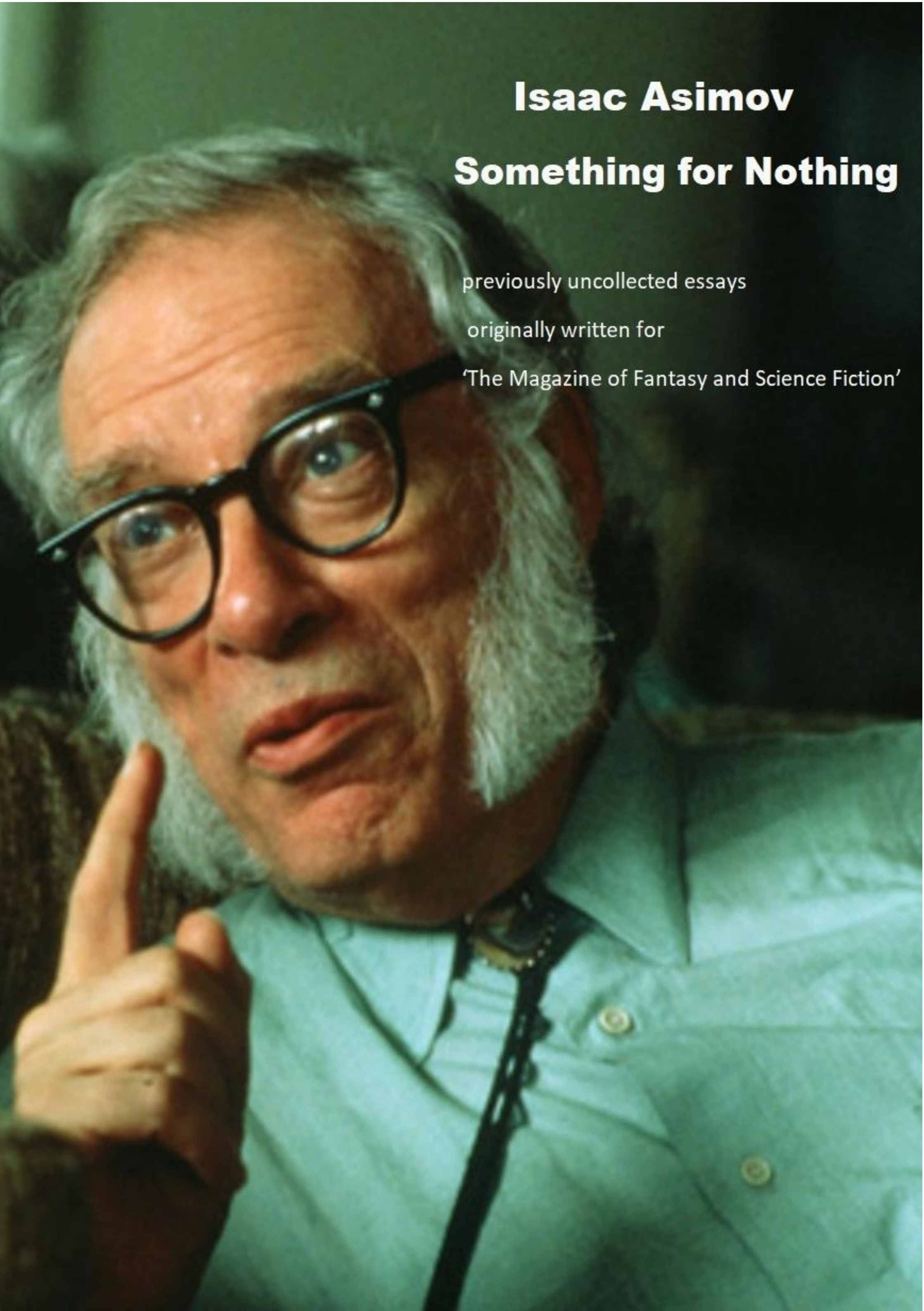

Isaac Asimov

Something for Nothing

previously uncollected essays

originally written for

'The Magazine of Fantasy and Science Fiction'

Contents:

SCIENCE

F&SF announces delightedly that it has managed to retain the rare insight, genial personality, and scientific erudition of the good Dr. Isaac Asimov, and that the intriguing results of his restless curiosity about physical phenomena and related matters will appear regularly in this new column.

In this issue, Dr. Asimov's column forms Part One of a rare kind of two-part feature. . . . It is not unusual for science fiction writers to take their cues from science fact articles—but in this case, A. Bertram Chandler's "Critical Angle" (on page 39) came in from a far corner of the world in the same mail that brought us this article from Boston. And so, by happy coincidence, we bring you first the facts on a little publicized subject, and then . . . a little more.

THE DUST OF AGES

by ISAAC ASIMOV

ONE OF THE DISHEARTENING DIScoveries a housewife makes early in housewifery (my hard-working wife tells me) concerns the unbeatability of dust. No matter how clean a house is kept and how little activity is allowed within it and how thoroughly children and other filthy creatures are barred from the premises, a fine layer of dust coats everything as soon as you turn your back.

The atmosphere of Earth, particularly in cities, is just plain dusty; and a good thing, too, or there would be no blue skies and no softening of shadows.

And space, particularly within solar systems, is also dusty. It is loaded with individual atoms and with conglomerates of atoms. Many of the conglomerates range up to pin-head size or so; the so-called "micro-meteors" which, at the velocities at which they move,

are large enough to do damage to a space-vessel. (One of the functions of the artificial satellite is to measure the quantity of such micro-meteors in circumterrestrial space.)

Their numbers, we hope, will not be high enough to impede space-travel, but they are high. The Earth sweeps up billions of them each day. They burn in the upper reaches of the atmosphere through friction-generated heat and never get within sixty miles of the Earth's surface. (The occasional large meteors that weigh pounds or tons are another story.) However, what is meant by "burn"?

In burning, the atoms composing the micro-meteors don't disappear, they merely vaporize with heat and then this vapor condenses to form an extremely fine dust. Slowly, this dust settles to Earth.

The most recent measurements of the atmosphere's meteoric dust (as far as I know) were reported by Hans Petterson in the February 1, 1958, issue of the British scientific journal, *Nature*. He travelled some two miles above sea-level on the slopes of Mauna Loa in Hawaii (and another mountain on Kaui) and sieved the air, separating out the fine dust, weighing it and analyzing it. At a two-mile height in the middle of the Pacific Ocean one can expect the air to be pretty free of terrestrial dust. Furthermore, Petterson paid particular attention to the cobalt content of the dust, since meteor dust is high in cobalt whereas Earthly dust is low in it.

He found 14.3 micrograms (about one two-millionth of an ounce) of cobalt in the dust filtered out of one thousand cubic meters of air. In meteors, some 2.5 percent of the atoms are cobalt so Petterson calculated that the total quantity of dust of meteor origin in the atmosphere, up to a height of 60 miles, amounts to 28,600,000 *tons.*

This dust isn't just sitting there. Slowly, it is settling to Earth while new dust is being added by the continuous entry of new micro-meters into the atmosphere. If the 28,600,000 tons is a steady figure, the same amount is being added each year as is settling out, but how much is that?

Petterson went back to data concerning the 1883 explosion of the Krakatoa volcano in the East Indies when tremendous quantities of the very finest dust were liberated into the upper atmosphere and sunsets were extra beautiful all over the world. Pretty nearly all that dust had settled back to Earth after two years. If this two-year-settling figure holds for meteor dust, too, then half the total—14,300,000 tons of such dust—settles to Earth each year and 14,300,000 tons of

new dust must enter the atmosphere.

At this point, Petterson ends his calculation and I begin mine—and the speculations that result concern our industrial civilization and the problem of landing on the Moon.

Naturally, 14,300,000 tons of dust per year seems like a large figure and the thought, to any housewife, would be a sobering one. However spread out over the Earth it's not so bad. The Earth has a surface area of about 197,000,000 square miles so the annual dust-fall per square mile is only about 145 pounds, which is nothing compared to the dust generated by the coal and oil we burn.

If we consider meteor dust to be mostly iron, 145 pounds is equivalent to 510 cubic inches (a cube eight inches on each side). Since a square mile contains about 4,000,000,000 square inches, a year's accumulation of dust spread out evenly over the square mile (or over the Earth generally, as a matter of fact) would pile up a dust layer about 0.00000013 inches thick. That's a trifle over a ten-millionth of an inch and even my wife wouldn't worry about that.

Of course, this goes on year after year and the Earth has been in existence as a solid body for a good long time; for perhaps as long as 5,000,000,000 years. If, through all that time, meteor dust had settled to Earth at the same rate it does today, then by now, if it were undisturbed, it would form a layer 54 feet thick over all of Earth.

It does *not* remain undisturbed, however. It falls in the ocean. It is blown about. It is rained on. It is tramped underfoot. Leaves fall on it.

And yet, this dust never disappears and it could be of the greatest importance to us. In comparison to the mass of the Earth, the 70,000,000,000,000,000 tons of dust collected in Earth's history is very little. It is only a hundred thousandth of the Earth's mass. *But*—the dust is mostly iron, and that makes it rather special.

The Earth, you see, consists of two layers, a central core of iron and materials soluble in it and an outer crust of silicates and materials soluble in it. This, presumably, dates back to the time when Earth was liquid and the two mutually immiscible liquids settled out, the dense one below and the lighter one above. In that case, though, why is there so much iron found in the Earth's crust among the silicates. Iron is actually the fourth commonest element in the crust.

Can this surface iron be, not Earth's original substance, but, at least in significant part, the accumulated meteoric dust of ages?

According to my calculations, the dust would account for all the iron in the upper 1½ miles of the Earth's solid crust, which certainly accounts too for all the iron we've managed to dig up Can it be, then, that the modern technology of our Age of Steel feeds entirely on the accumulated dust of space, like whales feeding on plankton? I wonder.

But what about the Moon? It travels through space with us and although it is smaller and has a weaker gravity, it, too, should sweep up a respectable quantity of micro-meteors.

To be sure, the Moon has no atmosphere to friction the micrometeors to dust, but the act of striking the Moon's surface should develop enough heat to do the job.

Now it is already known, from a variety of evidence, that the Moon (or at least the level lowlands) is covered with a layer of dust. No one, however, knows for sure how thick this dust may be.

It strikes me that if this dust is the dust of falling micrometeors, the thickness may be great. On the Moon there are no oceans to swallow the dust, or winds to disturb it, or life forms to mess it up generally one way or another. The dust that forms must just lie there, and, if the Moon gets anything like Earth's supply, it could be dozens of feet thick. In fact, the dust that strikes craters quite probably rolls down hill and collects at the bottom, forming "drifts" that could be fifty feet deep, or more. Why not?

I get a picture, therefore, of the first space-ship, picking out a nice level place for landing purposes, coming slowly downward tail-first . . . and sinking majestically out of sight.

SCIENCE

F&SF's youthful Science Columnist, who recently celebrated his 20th year as a science fiction writer, here offers a fascinating rundown on large numbers, their history, uses, and eccentricities. And, consistent with F&SF's policy of service, all brought to you comfortably in advance of income tax day.

LOVE THOSE ZEROES

by Isaac Asimov

I HAVE A TENDENCY IN THESE, MY articles, to get absorbed in large numbers. This leads to proofreading troubles, printers errors, and arguments from the readers. I risk all that for only two reasons: 1) In these days of atoms and space-distances, "astronomical figures" are becoming common property and everyone is beginning to use them; and 2) I love large numbers for their own lovely sake.

Of course, handling large numbers has its dangers. You can get lost among the zeroes and starve to death. So I'd like to take this occasion to hack away at the underbrush and clear a path, both for the sake of your curiosity and of my future articles.

All cultures have the problem of large numbers, varying only in the size of the large number. Some primitives, faced with five cows, would cautiously state the number of cows to be "many." The ever-so-clever Greeks and Romans went further but had no special name for any number higher than a thousand. The Greeks had a word "myrios" meaning "many" which the later mathematicians made over into "myrioi" meaning "ten thousand" which, to be sure, goes one step higher. The word has come down to us as "myriad," meaning "very many."

One could, of course, make the term "thousand" do for everything higher. As one rose upward in multiples of ten one could have "ten thousand" and "hundred thousand" (as indeed we do) then continue on with "thousand thousand," "ten thousand thousand," "hundred thousand thousand,"

"thousand thousand thousand" and so on ad infinitum.

Obviously clumsy.

After the crusades, when trade in Europe, and particularly in Italy, was beginning to flourish, merchants began to have occasion to think frequently in terms of thousand thousands. The Latin word for thousand was "mille," so some time in the 13th Century some nameless Italian decided on a slangy short cut for "thousand thousand" and called it "millione." The ending was intended to signify largeness, just as "balloon" is "large ball." In other words, "million" (which is the English version) means, so to speak, "king-size thousand."

It wasn't until the late 15th Century that "million" began to pass from trade into mathematics and even then it took another century before mathematicians could make up their mind that "million" meant "thousand thousand" rather than "thousand thousand thousand."

As you all know, the former won out.

Naturally, this sort of thing, once begun, is not easy to stop. Having invented "million" to do away with "thousand thousand," mankind was faced with the problem of what to do with "million million."

So, in the 15th Century, the word "billion" was invented in France. The "–illion" ending had already come to sound like big stuff. (It still does to youngsters who, having failed to learn to count to ten, are yet willing to bet a zillion skillion dollars.) As for the initial "b" in "billion," that is obviously part of the common Latin prefix "bi–" used to signify "two." After all, "billion" is the word "million" used twice.

This points the way for an indefinite extension of the system, an extension still used in England and Germany. Obviously a "million million million" is a "trillion"; a "million million million million" is a "quadrillion," and, in this way, we can build up, further, a "quintillion," "sextillion," "septillion," and so on. The prefixes in each case are Latin and signify, respectively, "three," "four," "five," "six," and "seven."

Since a million, in Arabic digits, is 1,000,000, you can see that each additional million in the name of the number, adds six zeroes. Consequently, to name a number according to the British-German system, just mark it off into groups of six, starting from the right.

For example, there are four sets of six zeroes in:

100/000000/000000/000000/000000

If we allow for the two zeroes left over to the left, the entire number becomes "one hundred quadrillion."

All this is nice, but it is not the system used in the United

States. Apparently what first upset the perfect logic of this going by sixes was the impatience of the Dutch merchants of the 17th Century. They saw no purpose in having "billion" mean "million million." Since they practically never made a million million gulden or sold a million million tulips, they had no use for such a number. So they used "billion to signify "thousand million" a smaller number which they found more useful.

This kind of corner-cutting had consequences. Once "billion" came to mean "thousand million," then "trillion" obviously meant, "thousand thousand million," "quadrillion" meant "thousand thousand thousand million," and so on. According to this system, a number would have to be divided up (starting at the right) into first a set of six digits, then as many sets of three as it will hold. Thus our earlier number would be:

100/000/000/000/000/000/000/000000

Counting the number of complete sets (both six and three) gives us seven. The Latin prefix equivalent of seven is "sept," so the number is "one hundred septillion" by this new system. If you count zeroes, you will see it is the same as the "one hundred quadrillion" in the English-German system.

This Dutch innovation leaked back into France which adopted it. The French had already invented the term "milliard" to express "thousand million." Since the French suffix "—ard" implies "something to excess," "milliard" is the equivalent of "very king-size thousand." Anyway, the French kept "milliard" but accepted the Dutch system otherwise.

Shortly after the American Revolution, when all things English were unpopular in the United States and all things French were popular, the Americans accepted the French system in place of the English (but with "billion" instead of "milliard") and have kept it ever since.

(The question of the value of the billion enters nuclear physics in an odd way. At the University of California in Berkeley they have built a tremendous atom-smasher capable of accelerating particles to several billion electron volts ("billion" being 1,000,000,000). The abbreviation of "billion electron volts" is "Bev," so the instrument is called the "Bevatron."

(However, the British can't accept that, of course. A Bevatron is no Bevatron to them, nor is a Bev a Bev. When they wanted to speak of a Bev they had to call it 1000 Mev (Mev standing for "million electron volts"). To avoid the thousand, they coined the abbreviation "Gev," which is short for "giga electron volts," the "giga" possibly being a slang abbreviation of "gigantic." Anyway,

NUMBER SYSTEMS (fine adjustment)

Number in digits	Number as Exponential	Name of Number: French-American system	Name of Number: English-German system
1	10^0	one	one
10	10^1	ten	ten
100	10^2	hundred	hundred
1,000	10^3	thousand	thousand
10,000	10^4	ten thousand	ten thousand
100,000	10^5	hundred thousand	hundred thousand
1,000,000	10^6	million	million
10,000,000	10^7	ten million	ten million
100,000,000	10^8	hundred million	hundred million
1,000,000,000	10^9	billion (milliard)	thousand million
10,000,000,000	10^{10}	ten billion	ten thousand million
100,000,000,000	10^{11}	hundred billion	hundred thousand million
1,000,000,000,000	10^{12}	trillion	billion

NUMBER SYSTEMS (coarse adjustment)

Number as Exponential	Name of Number	
	French-American system	**English-German system**
10^{6}	million	million
10^{9}	billion (milliard)	
10^{12}	trillion	billion
10^{15}	quadrillion	
10^{18}	quintillion	trillion
10^{21}	sextillion	
10^{24}	septillion	quadrillion
10^{27}	octillion	
10^{30}	nonillion	quintillion
10^{33}	decillion	
10^{36}	undecillion	sextillion
10^{39}	duodecillion	
10^{42}	tredecillion	septillion
10^{45}	quattuordecillion	
10^{48}	quindecillion	octillion
10^{51}	sexdecillion	
10^{54}	septendecillion	nonillion
10^{57}	octodecillion	
10^{60}	novemdecillion	decillion
10^{63}	vigintillion	
10^{93}	trigintillion	

one British Gev equals one American Bev. Remember that.

Of course, there is no reason why anyone has to follow this system all the way up. Billions have become familiar to all of us, thanks to the national budget. To science fiction readers, trillions have become familiar, if only because there are nearly six trillion miles in a light year. So why not break large numbers into the familiar billions and trillions? The number "one hundred septillion" (American system) can also be read "one hundred trillion trillion" or "one hundred million billion billion."

Scientists, who are the ones who most often have to use really large numbers, have, for the most part, abandoned the system of names altogether. Since our numbers are decimal in nature, each multiplication by 10 introduces a new zero. Thus, 10 is 10; 10 x 10 is 100; 10 x 10 x 10 is 1,000; 10 x 10 x 10 x 10 is 10,000; and so on.

The large number may then be written as simply the number of 10's it is necessary to multiply together. Thus, 10^3 is 10 x 10 x 10 or 1,000 and 10^6 is 10 x 10 x 10 x 10 x 10 x 10 or 1,000,000. Handily, the small number to the right and above the 10, the exponent, not only represents the number of 10's multipled, but also the number of zeroes in the final number.

Of course, though the exponential system is logical and precise, it lacks glamor. The Galaxy is 6×10^{17} miles wide but how much more resounding to say "six hundred quadrillion miles." There are 3×10^{25} water molecules in a quart of water but who can deny that "thirty septillion molecules" has more zing to it?

So with a sigh for the romance that lies dying under the heel of scientific nomenclature, I present two tables which summarize the sense of this article. Next time a kid offers to bet you a zillion dollars, raise him to a trigintillion. Not only will your word be a real number, but he will be jealous of you for having thought up such a beauty.

DUAL CEREBRATION

Said the Martian: "Our privacy's done,
For invasion from Earth has begun,
But those guys must be far
Less advanced than we are—
Two heads are still better than one."

—NORMAN R. JAFFRAY

The Good Doctor here discourses on the cumbersome character of calendars and suggests an improvement—in the course of which he reveals a surprising fact about the true date of Washington's birth.

ABOUT TIME

by Isaac Asimov

OCCASIONALLY, IN SCIENCE FICTION, WE ARE FORCED TO TAKE notice of the fact that once mankind spreads through various stellar systems, questions of calendar and time-keeping will arise. Sometimes, an author takes care of this by having an extra-terrestrial character say: "We live fifteen Xylchpian years, which is the equivalent of about two hundred and forty-five of your Earthly years." That shows he is at least aware of the problem.

Or else, the writer, early in the game, mentions something about Interstellar Time, or Galactic Standard, and then lets it go, the implication being that the time kept by people generally is equivalent to that kept on the Earth.

Well, that does seem pretty inevitable. Obviously, for matters confined to a newly colonized planet, it would be convenient to prepare a new time-scale in keeping with the planet's own peculiar motions. For instance, if the planet's day is equal to 23 Earthly hours, it would be reasonable to shorten the days, hours, minutes and seconds by 1/24 and keep all things as they have been. This would be Local Planetary Time and each planet could suit itself.

But for the sake of interstellar communication, transportation and trade, it would inevitably be wise to maintain some sort of uniform Galactic Standard Time after all. And that might very well be set equal to the Local Planetary Time of Earth. After all, things did get started here, and we have a long history and fair's fair.

Yet how nice it would be if the question of setting standards of time-keeping were to stimulate mankind into revising the whole system—at last—in the direction of reason and logic. In order to appreciate the *lack* of reason and logic under which we have labored throughout history, as far as time-keeping is concerned, let's take a quick look at our own Local Planetary Time.

We have three basic units of time, based on the motions of the Earth, Moon, and (in appearance) the Sun.

1) The "Solar Day" is the time from noon to noon, and is the period of rotation of the Earth (relative to the Sun).

2) The "Synodic Month" is the time from new moon to new moon and is the period of revolution of the Moon about the Earth (relative to the Sun).

3) The "Tropical Year" is the time from vernal equinox to vernal equinox and is the period of the (apparent) revolution of the Sun about the Earth.

Now these three units do not fit evenly together, the synodic month being equal to 29.530388 days, and the tropical year to 365.24220 days. It follows that any calendar which tries to handle all three is going to have its problems.

Yet early man needed some handy unit of time greater than a day, and the moon, with its prominent phases, was certainly a natural keeper of time. Once he got the idea that the various phases of the moon appeared with unvarying regularity, he was set. Instead of trying to count days, he could count moons and find his days in convenient chunks.

It seemed neatest to begin the month with the new moon (which in primitive times was considered to be a "new" moon in the literal sense). It was only natural, then, to watch evenings for the first appearance of the crescent moon immediately after sunset; and that sunset could be considered as the beginning of a new month.

Since the synodic month is approximately 29½ days long, successive crescent moons will be sometimes 29 sunsets apart and sometimes 30, pretty near alternately. Occasionally, because the synodic month was a trifle over 29½ days long, there might be two 30-day months in a row but this wasn't too bad. If you simply followed the moon, you couldn't go wrong.

The job of keeping track of the moon usually devolved on the priesthood (as being a conscientious and learned group, skilled in the arts of propitiation of gods and demons and with nothing much else to do anyway). Furthermore since time-keeping was found to be important to

proper methods of agriculture, and hence a matter of life and death, the time of the new moon became a matter of rites and ceremonies not to be dismissed lightly.

Even after astronomers worked up accurate mathematical formulas to predict in advance the night of the appearance of successive new moons, the priesthood went through the time-honored (pun intentional) ceremonies. The Roman high priest, the "pontifex maximus," for instance, officially proclaimed the first appearance of the new moon each month, and since the Latin word for "proclaim" is "calare," the first day of the month was called the "calends" and a table of months is now called a "calendar."

Furthermore, the phases of the moon could be most easily distinguished at four prominent stages: new moon, first quarter (half moon on the increase), full moon, and last quarter (half moon on the decrease.) These are 7.382597 days apart or, rounding off to the nearest whole number, 7 days apart. The Babylonians therefore divided the month into 7 day portions for easier handling. The Jews picked up that habit during the Babylonian captivity and the early Christians inherited it and spread it to the Graeco-Roman world. As a result, we now have the unit of time called the "week."

The use of such a purely lunar calendar turned out to be a rough guide to the seasons (as mankind must have quickly learned) and this was what made it to valuable to farmers. Every twelve months it was (roughly) planting time again, or harvest time again, or sunstroke time again, or blizzard time again. Perhaps it was this fitting of twelve months into one cycle of seasons that made twelve such a popular magic number (twelve signs of the Zodiac, twelve tribes of Israel, twelve labors of Hercules, etc.). That, and the fact that by good chance, 12 happens to be the smallest number that is evenly divisible by 2, 3, and 4 (and 6, too). To societies that have not learned how to handle divisions that don't come out even, this is an important factor. (Again the pun is intentional. All my puns are intentional.)

But there was a flaw in this, based on the fact that the lunar month and the tropical year are not commensurable and it is the tropical year that governs the seasons, not the lunar month. Twelve synodic months do not make exactly a tropical year. Twelve synodic months equal 354.364656 days which is 10.87755 (call it 10⅞) days short. After twelve lunar months have passed, 10⅞ days must pass in addition before the Sun is back in position, say of equinox or of solstice. After two sets of twelve lunar months have passed, 21¾ days must pass before the Sun is back in position. After three sets of twelve lunar months

have passed, roughly one additional lunar month must pass and so on.

Each lunar year (made up of twelve lunar months) falls further behind the seasons. By the time 18 lunar years have passed, the month that originally marked planting time now marks harvest time while the month of sunstroke has become the month of blizzards. Another 18 lunar years and once more they mark planting time and sunstroke time respectively.

This is annoying and a bothersome complication for farmers, who must live by the seasons, yet some groups keep the lunar months untouched and let the seasons fall where they will. The Mohammedan calendar is of that type, losing three full laps on the seasons every century. It is for this reason that the fasting month of Ramadan, when loyal Moslems may not touch water from sunrise to sunset, will every generation work its way through the hottest time of the year, to the vast discomfort of all.

Usually, however, a society with such a lunar calendar will not allow the seasons to fall out of step. They will wait until the months have fallen a full month behind the seasons and will then add an additional or "intercalary" month. Naturally, they will try to find some regular or automatic way of doing this.

The Hebrew calendar, for instance, groups the tropical years into sets of 19 (because 19 tropical years equals almost exactly 235 synodic months so that the twentieth year starts off from scratch with a new moon). Nineteen groups of 12 synodical months, however, comes out to 228 synodic months, so 7 intercalary months must be added here and there to keep things even. This is done by adding an intercalary month to the 3rd, 6th, 8th, 11th, 14th, 17th and 19th year of each set of 19. The Jews inherited this calendar from the Greeks and although it sounds complicated, it manages to keep time.

The Egyptians were the first to establish the fact that the tropical year was roughly 365 days long and they were also the first to abandon the moon and to arbitrarily lengthen the month to a flat 30 days. This meant the new moon drifted through the months and only rarely came at the beginning of the month, but the Egyptians didn't care. As long as they could foretell the date of the Nile flood easily by just looking at the calendar (the Nile flood following the Sun and not the Moon), the Moon could go to the devil. Of course, twelve months of 30 days each, comes to only 360, but the Egyptians added 5 holidays at the end, and that was that. This extraordinarily simple calendar was not adopted by other peoples because of the religious connotations that had grown about the month, which made it nearly untouchable.

Besides, the tropical year is actually about 365¼ days long so that every four years, the Egyptian calendar fell a day behind the Sun, and every 1460 years, it lost one full lap on the Sun. The Egyptian calendar worked its way through the seasons as the Mohammedan calendar did, but much more slowly. In the time of the Ptolemies, the Greek astronomers in Alexandria tried to reform the Egyptian calendar to allow for the quarter day but the Egyptian people would have none of it. What was good enough for their great-great-great-great-grandfathers was good enough for them.

Rome, meanwhile, had a perfectly miserable lunar calendar which the priestly class had allowed to fall into complete disorder. Julius Caesar therefore introduced the Egyptian calendar, *with* the refinement (thanks to his Alexandrian adviser, the astronomer Sosigenes) of a leap year, containing 366 days, every fourth year. On the debit side was the disruption of the even-lengthed months of the Egyptians and the substitution of an exasperating system whereby months have any number of days from 28 to 31.

This "Julian Calendar" has persisted until modern times, but it has its flaw, too. A leap year of 366 days every fourth year implies a tropical year of 365.25 days long on the average, when the true length is 365.24220 days. The Julian Year is, in other words, 11 minutes too long and every 128 years it gets a day ahead of the Sun. During the first few centuries of its existence the calendar was occasionally tinkered with and set to rights, but by the final days of the Roman Empire it was let loose to work automatically and by the 16th century, it had gained ten days on the Sun.

This was throwing a serious crimp into the Church holy days. The Church authorities realized that if this went on, then, after a few millennia, Easter would be coming in mid-summer and Christmas would be a spring festival.

So, in 1582, Pope Gregory XIII dropped ten days and set the year even with the Sun. To keep it from falling out of step again, he decreed the removal of three leap years every four centuries. That is, even century years not divisible by 400 were not to be leap-years. Thus, 1900 was not a leap-year in the Gregorian calendar, but was one in the Julian calendar. The year 2000, being divisible by 4 *and* by 400 will be a leap-year in both calendars.

The new Gregorian calendar is quite good. It assumes a year that is, on the average, 365.2425 days long. This is only 25 seconds longer than the true value of the tropical year, so that our present calendar won't gain a full day on the Sun for 3,400 years.

Protestant and Greek Orthodox countries hesitated to follow the Pope in this. Great Britain (and the American colonies) didn't make the change till 1752, by which time the Julian calendar had gained an eleventh day on the Sun, since the year 1700 was a leap year in the Julian but not in the Gregorian calendar. Eleven days were dropped while crowds rioted and yelled to have them back.

Russia didn't switch till after the 1917 Revolution and had to drop 13 days, two more having been gained in 1800 and 1900. The Orthodox Church, however, still holds to the Julian calendar to this day, which is why the Orthodox Christmas and Easter don't coincide with the days usually celebrated in the Western world.

(Incidentally, if you want to win an easy bet, offer a wager that Washington wasn't born on Washington's Birthday. He wasn't. He was born on February 22, 1732 by the Gregorian calendar, but when he was born, the colonies were on the Julian calendar, and the church records therefore record him as having been born on February 11, 1732.)

As for periods less than a day, we are the victims of the Babylonians. Day and night were considered separately until Roman times. (Hence the Bible in the first chapter of Genesis, carefully explains that the individual "days" of creation include both days and nights. For instance, verse 5, says "and the evening and the morning were the first day," verse 8 says "and the evening and the morning were the second day," and so on.)

Both day and night were divided into 12 hours (there's 12 again). Then, once time telling became accurate enough in the middle ages and early modern times, the hour was divided into 60 minutes and the minute into 60 seconds, by analogy with the divisions of the degree. The degree is the unit used to measure the movements of the heavenly bodies and since time-telling is based on heavenly motions, the analogy seemed obvious. And why by 60? Well, that was introduced by the Babylonians, probably because 60 was so convenient, being the smallest number capable of even division by 2, 3, 4, 5, and 6 (also by 10, 12, 15, 20, and 30.)

And so we have a most miserable set of units of time, related to one another in all sorts of odd ways. To summarize:

60	seconds	=	1 minute
60	minutes	=	1 hour
24	hours	=	1 day

7	days	=	1 week
4 to 4 3/7	weeks	=	1 month
12	months	=	1 year

Nowhere in the list is there to be found the one factor which is made natural by the anatomy of our hands and by the consequent structure of our number system—ten. This only occurs for units of time longer than a year (10 years make a decade, 10 decades a century, and 10 centuries a millennium) and for units of time shorter than a second (a millisecond is a thousandth of a second, and a microsecond is a millionth of a second).

These units above a year and below a second are rarely used in every day life, however, and for those units we deal with constantly there is no trace of a decimal system. And that means endless difficulties.

For instance, one of the most common and necessary usages of time-units is the calculation of time-lapse. If you are cooking, or running scientific experiments or keeping an appointment or allowing for travel-time, you might want to know what the time lapse is between 3:15 P.M. (which is the time you're aiming at) and 11:37 A.M. which is, let us say, the current time.

If it were a usual problem in arithmetic you would say: 3:15 minus 11:37, and where would that get you? Even if you adopt the armed services system and refer to the later time as 15:15, that would leave you with 15:15 minus 11:37 or 3 hours and 78 minutes by ordinary arithmetic, which is nonsense by the clock. The correct answer is 3 hours and 38 minutes. It gets even more complicated if you throw in seconds.

Then suppose you want to know the lapse of time between two dates, as bankers and astronomers and accountants often do. How many days between February 15 and May 3? Go ahead. How many? You have to work it out on your fingers or get a calendar and start figuring. Suppose you write the dates using figures for months. May 3 is 5/3 (or 5/03, if you prefer) and February 15 is 2/15. Well, then, how much is 5/03 minus 2/15? Ordinary arithmetic will not give you the correct answer of 77 days (or 78 if it is Leap Year).

If you have a calendar that gives you the individual number of each day, that would help but only if the two dates were in the same year.

What needs to be done to bring time-telling into line with ordinary arithmetic is to make time-telling a thoroughly decimal manipulation. This can't be done if we're going to use three different incommensurable

fundamental units. So let's just pick one; the most fundamental one —the day.

To begin with, let's divide the day by tens. To keep things as familiar as possible, we can use the old names for the time division, but in honor of the new decimal arrangement, let's prefix the word "metric" to those names. In other words, each day can be broken up into 10 "metric hours," each metric hour into 100 "metric minutes" and each metric minute into 100 "metric seconds." These can be broken down to "metric milliseconds" and "metric microseconds" if you wish, but I'll quit at the metric seconds.

Working upward, 10 days make a "metric week," 10 metric weeks a "metric month," and 10 metric months a "metric year." Year can continue on to "metric decades," "metric centuries" and "metric millennia" if you wish, but I'll stop at metric years.

Let's summarize this in a small table, indicating the relationship between these metric units and our ordinary time units.

Metric units	ordinary units				
1 metric year	1,000	days	=	2.74	years
1 metric month	100	days	=	3.32	months
1 metric week	10	days	=	1.43	weeks
1 day	1	day			
1 metric hour	0.1	day	=	2.40	hours
1 metric minute	0.001	day	=	1.44	minutes
1 metric second	0.00001	day	=	0.86	seconds

Are you wondering whether all this is really necessary? (I'll bet the kindly editor is.) Well, perhaps not necessary, since we've gotten along without it so many years, but consider how convenient it would be.

If one event happens at 2/15/35 of the day in metric time units (that is, 35 metric seconds after 15 metric minutes after 2 metric hours after the beginning of the day) and the second event is to happen at 9/08/12, then the time lapse is 9/08/12 minus 2/15/35, or 6/92/77; or 6 metric hours, 92 metric minutes and 77 metric seconds; a result achieved by ordinary arithmetic without frills.

Naturally, in such a system, the first metric hour of the day should be numbered 0, as should the first metric day of the metric week, the first metric week of the metric month and so on. This may sound queer but it is the logical way of doing it, and only sounds queer because we have been illogical for so long. The first minute of the hour *is* numbered 00 even in our ordinary system. For instance, the time repre-

sented by 15 seconds after 6 A.M. sharp is written 6:00:15. In the case of minutes and seconds we happen in this respect to be logical.

The days of the metric year can be numbered in logical fashion. The 16th day of the first metric month would be 0/1/6 (that is, 1 metric week and 6 days after the beginning of the year) while the 54th day of the seventh metric month would be 7/5/4 (7 metric months, 5 metric weeks and 4 days after the beginning of the year.) The time lapse between the two would be 7/5/4 minus 0/1/6, or 7/3/8; that is, seven metric months, three metric weeks, eight days, obtained by ordinary arithmetic.

You can leave out the shilling marks and combine units of days and more, with units less than a day by using a decimal point. Thus 754.21535 would be 7 metric months, 5 metric weeks, 4 days, 2 metric hours, 15 metric minutes and 35 metric seconds after the beginning of the year.

You can switch from one unit to another by just shifting the decimal point. Thus 754.21535 days is equal to 75.421535 metric weeks or to 7.5421535 metric months or to 0.75421535 metric years. Pushing the decimal point the other way, 754.21535 days is equal to 7542.1535 metric hours, 754215.35 metric minutes and, of course, 75421535 metric seconds.

The last day of the metric year would be numbered 999, and the day after would be 1000. Write it 1/000 and it would clearly be the first day of the second metric year (the first metric year would have the number, 0, of course). You could continue right up through the metric years and have 22/154 or 573/038 and so on.

Yet, though all this is arithmetically neat and clean, you may wonder about the seasons? The metric units do not fit the seasons at all and everybody would need a conversion table to know at what time (or times) in a given metric year to expect hot weather or blizzards or harvest moons or spring fever and all the rest of it.

Ah, but it is a Standard Galactic time I am talking about, and not Local Planetary time. I'm suggesting a time scale to be used by all the planets of the Milky Way, which will all have different seasons of different sorts anyway.

And yet—

And yet the funny part of it is that this very system I have been describing is in use today right here on Earth. Let me explain.

At the time that the Gregorian calendar was being introduced, various conservative people found the change in date confusing, and one

astronomer grew sick of the whole mess. He was an Italian named Joseph Justus Scaliger.

He reasoned that months and years had been shifted and shifted until no one could ever calculate the time-lapse between two dates without incredible tedium. Yet in following the motions of the heavenly bodies, astronomers (and astrologers too) had to know that time-lapse. Well, the one time unit that had never been fooled with was the day itself. Why not, thought Scaliger, simply number the days and be done with it.

The only difficulty was to find a particular day that would do as Day 1. Naturally, such a day should be far enough in the past so that astronomers would not be very likely to run into negative day numbers in keeping their records, in calculating backward for eclipses and so on. Nor should it be too far back, lest the number assigned to modern days be needlessly large.

What Scaliger did, then, was to take what was called the "Julian Cycle" which consisted of 7,980 Julian years. In such a cycle there are an even number of synodic months and a few other units of time much used by the ancient world. In other words, a number of varieties of time-measure all started from scratch simultaneously every 7,980 years.

Calculating backward, it turned out that the last time they had all started from scratch was on January 1, 4713 B.C. (They will all be at the starting post again, therefore, on January 1, 3267 in the Julian calendar, which will be about March 1, 3267 in the Gregorian calendar.)

Scaliger therefore suggested that January 1, 4713 B.C. be assigned the number, 1 (I wish he had assigned it 0, to be completely logical) and that all days be numbered consecutively thereafter. This system is now used in astronomy and each day has its own number which is independent of the type of calendar, whether lunar or solar, whether Julian or Gregorian. This number is called the "Julian Day." (That sounds as though it has some connection with the Julian calendar or with Julius Caesar, but it hasn't. Scaliger, in a fit of filial piety, decided to name the system in honor of his father, Julius Scaliger.)

The Julian Day begins at noon and is broken up into tenths, hundredths, thousandths and so on, rather than into hours, minutes and seconds. Thus, 3:15:30 P.M. of Julian Day 125 would be 125.13580. This is the actual way in which astronomers would record that time and this is equivalent to my system of saying it is 1 metric hour, 35 metric minutes and 80 metric seconds after the start of Julian Day 125

Now let's look a little further. The stock market crash took place on October 29, 1929, the attack on Pearl Harbor on December 7, 1941, the invasion of Korea on June 24, 1950, and I am writing this article on November 23, 1959. To calculate the time lapse between any of these dates to the nearest day is tedious.

But each of these dates has a Julian Day number associated with it, and, if my own calculations are correct, here they are:

October 29, 1929	—J.D. 2,425,914
December 7, 1941	—J.D. 2,430,336
June 24, 1950	—J.D. 2,433,457
November 23, 1959	—J.D. 2,436,896

These numbers fit in with my metric time units of course. The stock market crash took place 2 metric millennia, 4 metric centuries, 2 metric decades, 5 metric years, 9 metric months 1 metric week and 4 days after the beginning of the Julian Day cycle. Or, if you prefer, it happened 2425.914 metric years after, or 914 days after the beginning of metric year 2,425.

Anyway, suppose calendars carried Julian Days with each date and that when dates were given in histories or in almanacs, the Julian Day number was also included. How simple it would be to know that, as I write, the stock market crash was 10,982 days ago (or, if you prefer, 10.982 metric years ago) that the time lapse between our entry into World War II and the start of the Korean war was 3,121 days (or 3.121 metric years).

And to top it off my own age as of now (November 23, 1959) is exactly 14.570 metric years. You have enough information now to calculate out the date of my birth, but you needn't! That date is getting to be disgustingly far back in time and I'd rather not be reminded. [1]

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[1] I am even older, by just a few days, than the kindly editor.[2]

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[2] The Good Doctor's customary phenomenal accuracy deserts him here—"few" is hardly the just word.—THE KINDLY EDITOR [3]

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[3] All right—forty lousy days.—THE GOOD DOCTOR

There has been much loose talk to the effect that it is impossible to exceed the speed of light, which is of course absurd. As the Good Doctor shows, we've been doing it for years.

THE BUG-EYED VONSTER

by Isaac Asimov

IN NOVEMBER 1959, A BEAUTIFUL NEW PROTON SYNCHROTRON was put into operation in Geneva, Switzerland, with a 3500 ton magnet and a peak power of 38,000 kilowatts. It is nearly three city blocks in diameter and is about 2/5 of a mile in circumference. It cost $30,000,000.

All this is easy to marvel at and newspaper stories have *tsk-tsked* at all the statistics with vehemence. The whole point of the thing, however, is that it produces particles with energies of 24 to 30 Bev—and this is *tsk-ed* at, too, but the articles never bother to explain what a Bev is beyond sometimes saying it is an abbreviation for "billion electron volts," and then they never explain "electronvolt." (I, myself, as an old science fiction hand, always have the urge to read Bev as "bug-eyed vonster" and I am hoping to exorcize the urge by using the phrase as the title of this article.)

I'm telling you this time, then (tears of gratitude enter the soft[1] blue eyes of the Kindly Editor whenever I choose to be topical), about the problem of the electron-volt in connection with this glorious new instrument of science, and will touch on a few other allied topics which will undoubtedly arise.

[1] Some observers have used the word "soggy" in this context, others, "poached," or "despairing"—but I offer no explanations in print.—THE KINDLY EDITOR

A charged particle moves through an electric field and gains kinetic energy doing so, just as you would gain kinetic energy if you moved through a gravitational field, as in falling from an airplane. The amount of energy gained in the process (in either case) depends on the mass of the moving object and the velocity attained. The velocity attained depends in turn upon the intensity or potential of either type of field. (Thus, as you know, you would fall more quickly and land with a splashier thud in a plane-fall on Earth than one on Mars, which planet has a lower gravitational potential.)

For particle energies, physicists make use of the electron as the unit of mass (it being the lightest charged particle) and the volt as the unit of electrical potential (it being the most common unit). An electron falling through an electric potential of one volt gains one electron-volt of energy. What could be more straightforward?

But that still doesn't tell us how much energy an electron-volt represents. I could explain by saying that an electron-volt equals 1.60×10^{-12} ergs (or somewhat over a trillionth of an erg, if you prefer words to figures) but does that help? Few of us can picture an erg either.

However, there's a way out of the impasse! Let's begin by considering that the value of the kinetic energy of any object can be related to its mass and velocity by the following equation:

$$e = \tfrac{1}{2}mv^2 \qquad \textit{(Equation 1)}$$

where "e" represents kinetic energy, "m" represents the mass, and "v" the velocity of the moving body. If the mass is measured in grams and the velocity in centimeters per second, then the kinetic energy comes out in ergs.

This equation can be applied easily to a proton with a kinetic energy of 1 electron-volt. The mass of a proton is 1.66×10^{-24} grams, and the kinetic energy, as I have just said, is 1.60×10^{-12} ergs. Substituting those values for "m" and "e" respectively in Equation 1, and solving for "v" we get the answer 1.4×10^6, or 1,400,000 centimeters per second. In our common units, this comes, roughly, to 8.7 miles a second.

There, I think, is a clear picture of an electron volt. It represents the kinetic energy of a proton speeding along at 8.7 miles a second, a velocity somewhat greater than that of a moon-probe rocket.

Since kinetic energy is proportional to the square of the velocity, a proton at double the electron-volt velocity (which is therefore moving at 17.4 miles a second) would have an energy of 4 electron-volts; one

moving at 34.8 miles a second would have an energy of 16 electron-volts; and so on.

Back in the 1920's, when physicists were trying to smash atomic nuclei by bombarding them with energetic particles, they first used alpha particles fired out of naturally radioactive substances. Then they tried to accelerate protons in high-potential electric fields in order to get a larger, cheaper and better supply of energetic particles.

The first physicists to produce protons with sufficient energy to bring about nuclear reactions were John D. Cockroft and Ernest Walton in England. In 1928, they used what they called a "voltage multiplier" to build up an electric potential high enough to produce protons of nearly 400,000 electron-volt energies. Such protons move at velocities of 5,500 miles a second.

In America, in the 1930's, Robert Jemison Van de Graaf, used structures shaped like half a dumbbell set upright and within them created higher potentials still so that eventually he could produce protons with energies as high as 4,000,000 electron-volts. As particles in the millions of electron-volts became common, physicists avoided the use of an overabundance of zeroes, by adopting a derived unit, the Mev (for "million electron-volts.")

One Mev, naturally, is equal to 1.60×10^{-6} ergs, or to rather more than a millionth of an erg. A proton with an energy of 1 Mev travels at a velocity of 8,700 miles a second.

But the principle of creating energetic particles by building up ever higher potentials reached as high as it could profitably go with Van de Graaf. An alternate principle that came in about 1930 took over. Instead of energizing protons by yanking them on under the pull of a huge potential, small potentials were used over and over again.

This is analogous to a situation involving a child in a swing. You might send the child high into the air by giving him a mighty push. Or you might do the same by giving him a small push every time he comes down and starts up again. The small pushes would add up over a period of time and eventually send him flying high without your ever having had to exert yourself unduly at any one time.

In the latter case, however, the series of pushes must be carefully synchronized. If you push the child on the swing while he is still moving backward and before he has started his natural forward motion, you will slow the swing rather than speed it.

In the early 1930's, "linear accelerators" were built, in which the speeding proton moved through a succession of cylinders, in each one

of which it got a new potential push. The difficulty lay in so timing the potential pushes that the proton got a kick forward each time it entered a new cylinder and not an undesired kick backward.

Ernest Orlando Lawrence got around this difficulty by introducing a magnet, the presence of which caused the flying protons to travel in a curved path (so that the instrument was named a "cyclotron.") For reasons I won't go into, it is easier to synchronize the potential pushes as the proton goes flying round and round the instrument, giving it a new push twice every revolution. With each push it travels more quickly and as it speeds up, it curves less and less under the influence of the magnetic field so that it travels in an expanding spiral. Eventually, protons spiral out of the instrument altogether and smash into their target with whatever energy they had gained in the interval.

Lawrence built his first cyclotron in 1931, a home-made job less than a foot in diameter, which could nevertheless produce protons with energies of nearly 1¼ Mev. By 1939, a large cyclotron at the University of California (Lawrence's home-base), five feet across, was producing 20 Mev. protons.

Using Equation 1, we can calculate that a 20 Mev proton is travelling at a speed of 38,500 miles a second. If it were travelling at this speed in a straight line, it would reach the Moon in a trifle over six seconds. Unfortunately, Equation 1 is only an approximation, one which works at low speeds but not at high. Now that we're pushing the proton into the sort of velocity involved in the Mev range of energies, something new must be added.

In using Equation 1 to calculate the kinetic energy at varying velocities, or vice versa, it is naturally assumed that the value of the mass, "m," remains constant as velocity varies.

But it doesn't. As long ago as the 1890's, the Dutch physicist, Hendrik Antoon Lorentz, showed that the mass of a charged particle increased with velocity, according to the following equation:

$$m^* = m/\sqrt{1 - v^2/c^2} \qquad \textit{(Equation 2)}$$

where "m" is the mass of a body at rest, and "m*" is its mass when it is moving at velocity "v." The symbol "c" represents the velocity of light in a vacuum. (A decade later, Einstein advanced his theory of relativity which showed, among other things, that this increase of mass with velocity applied to all objects and not merely to charged particles.)

The velocity of light in a vacuum is 186,282 miles a second, and this is so high that for any ordinary values of "v" (say, a few miles a second or even a few thousand miles a second), the expression "v^2/c^2" is equal to nearly zero, so that "$1-v^2/c^2$" and its square root, are both equal to just about 1. Therefore, for any value of velocity less than, say, 10,000 miles a second, "m^*" is just about equal to "m."

That means that in all ordinary aspects of life, mass might just as well be considered as not varying with velocity, and Equation 1 will do for everything. It was only with the discovery of radioactivity and super-speedy subatomic particles, which was the first time mankind ever came up against velocities of over 10,000 miles a second, that the approximation turned out to be insufficient.

By the time protons of 20 Mev energy were obtained in the cyclotron, the use of Equation 1 would lead, as I said, to a calculated proton velocity of 38,500 miles a second, or a respectable 20 percent of the speed of light. But using equation 2, it turns out that a proton travelling at such a speed has a mass equal to 1.06 times its mass at rest.

With such an increase in mass, it is no longer sufficient to calculate the velocity of such particles by Equation 1, because at energies in the Mev range a significant part of the energy is represented in increased mass rather than in velocity. Equations 1 and 2 may be combined:

$$e = \tfrac{1}{2}mv^2/\sqrt{1 - v^2/c^2} \qquad \textit{(Equation 3)}$$

Using Equation 3, it turns out that a 20 Mev proton has a speed of only 36,200 miles a second.

But the mass increase throws off the cyclotron. The cyclotron administers its synchronized pushes on the principle that the increased energy of the particle would go entirely into increased velocity. At 20 Mev, however, the protons are travelling at only 94 percent the velocity they "ought" to be travelling at, and the pushes are falling out of phase. The protons were beginning to be slowed rather than hastened and energies of much past 20 Mev did not seem possible unless something was done.

Something *was* done. In 1944, a Russian physicist, V. I. Veksler, designed a modified cyclotron in which the electric potential was slowly decreased as the mass of the speeding protons increased so that the synchronization of pushes was just maintained. By the 1950's, such "synchrocyclotrons" were producing protons with energies of up to 800 Mev.

Using Equation 3, it turns out that an 800 Mev proton is travelling at about 125,000 miles a second (⅔ the speed of light) and has a mass equal to 1.8 times its rest mass.

Even the synchrocyclotron, however, has its limit. As the protons spiral out and out, they eventually escape from within the magnetic field of the instrument and then no more energy can be piled into them. Fortunately, in the early 1940's, devices called "synchrotrons" had been designed and built for the acceleration of electrons. In these, the stream of particles was made to travel in a true circle and not in a spiral. The stream was kept within the magnetic field longer than would otherwise have been possible and the energy could be built up to extraordinary high levels. At the desired moment, a transient change in the magnetic field was introduced, and a pulse of high-energy particles was sent out of the instrument and into the target.

This principle was adapted in the early 1950's to protons and so came into being the most powerful type of atom-smashers yet built, the "proton synchrotron."

With such instruments, energies of over 1,000 Mev were attained for the first time. Since 1 Mev equals 1,000,000 electron-volts, 1,000 Mev equals 1,000,000,000 electron-volts, or (in the United States, at least) one billion electron-volts. For that reason 1,000 Mev can be set equal to 1 Bev.

One Bev is the energy equivalent of 1.60 x 10^{-3} ergs, or something over a thousandth of an erg, and this is a tremendous amount of energy to concentrate into a single particle. The particles in cosmic rays have energies of this amount and higher, however, so when the proton synchrotron at Brookhaven was built in 1952 and found capable of producing energies of between 2 and 3 Bev, it was called the "Cosmotron." A larger instrument at the University of California, produced particles of between 5 and 6 Bev and was called the "Bevatron." An instrument in the Soviet Union called the "Phasotron" produces protons with energies up to 10 Bev, and, of course, the new Geneva instrument can reach up to 30 Bev, while instruments now building are expected to reach 50 Bev.

By the time energies in the Bev region are attained, most of the additional energy being piled into the particles goes into an increase in mass rather than into an increase in velocity. The maximum possible velocity is that of light in a vacuum. At that velocity, we are setting "v" equal to "c," and "v^2/c^2" consequently equals 1. This means that "$1 - v^2/c^2$" and its square root are both equal to zero.

If you go back to Equation 2 now, you will see that this means that at the speed of light, "m^*" is equal to "m/o," which is a way of saying that mass grows infinite at the speed of light. Checking with Equation 3, you will see that, in the same way, the kinetic energy of any object grows infinite at the speed of light.

This is one of the reasons why it is logical to suppose that the speed of light in a vacuum is the maximum possible velocity, since to have a greater velocity would entail a more than infinite mass and a more than infinite amount of kinetic energy, both of which are unthinkable.

Already at 800 Mev, the velocity of the proton has reached ⅔ that of the speed of light. At 10 Bev, the protons are flying at a speed of just about 186,000 miles a second (nearly 99.9 percent of the speed of light) and have masses equal to about 20 times the normal rest mass of the proton.

For greater energies, there can be practically no further increase in velocity; an additional couple of hundred miles a second at most, and this can be ignored. Almost all the additional energy goes into mass. If the energy is doubled, the mass is doubled.

But if we really want to marvel, we must turn away from man-made devices and consider the heavens. The most powerful instruments yet conceived can't light a candle to some of the particles in cosmic rays. To be sure, most of those particles have energies in the lower Bev range, but a small percentage of them attain much higher energies; even unbelievably high energies.

The most energetic cosmic ray particles yet measured have the fantastic energy count of 5,000,000,000 Bev. Fewer than one cosmic ray particle out of a hundred trillion is that energetic, but there are enough of them to make them worth considerable study.

Such a super-energetic cosmic ray particle, travelling virtually at the speed of light would have a mass equal to ten billion times the rest mass of a proton. (This would still be equal to only about a hundred-trillionth of a gram, however.) Further, such a particle must have as much energy concentrated into its tiny size as would be represented by an ounce weight travelling at 18 miles an hour.

(This sounds like a formidable matter. The bombardment of Earth by the equivalent of ounce weights travelling at 18 miles an hour makes it seem as though there ought to be occasional casualties; brain concussions at the least. Of course, it's not really that bad. An ounce weight with that energy, striking your head suddenly, would transfer all its energy, minus some energy of rebound, to your skull with sad results.

A cosmic ray particle with that same energy would go right through you, losing little, if any, energy in the process. It's the energy you *absorb* that does the damage. Of course, the cosmic ray particle may deliver just a smidgeon of energy to a key protein molecule in the brain and do some subtle damage that will shorten your life but that's another story.)

Right now, there is considerable interest in the superenergetic cosmic ray particles because information concerning them may decide between two competing theories as to cosmic ray formation. In both theories, the cosmic ray particles are supposed to originate from stars as a result of particularly energetic nuclear reactions taking place.

The first theory supposes that cosmic ray particles are shot out with energies in the lowest range, say not more than 1 Bev. Such energies could easily be produced by a supernova. As these particles pass through the small magnetic field associated with the Galaxy, and other fields associated with stars, they travel complicated spiral paths picking up energy as they go, just as though the Galaxy were a super-colossal cyclotron.

As they travel, they may collide with stars or planets and be taken out of circulation. The longer a cosmic ray particle remains on its travel, the more energy it piles up, but also the greater its chances for coming to the end of its road. For that reason, the cosmic-ray particles Earth encounters include many low-energy particles, fewer higher-energy paricles, still fewer still-higher-energy particles and so on.

Meanwhile, as a particle gains in energy, its path becomes less curved. Eventually, its path is so uncurved that it passes outside the limits of the Galaxy (as a proton may pass outside the limits of a cyclotron) and be gone forever.

That, as I say, is the first theory.

The second theory is that the cosmic ray particles are originally produced with the energies they possess when we encounter them. This is a far less likely theory than the first because the most energetic reactions we can imagine on the basis of present knowledge (say the collision of an anti-matter star with a star of ordinary matter) could produce only about 250 Bev particles. Nothing we can imagine can produce a 5,000,000,000 Bev particle from scratch. But that is just what makes the second theory fascinating. If, against all expectations, it should turn out that the second theory is correct, it would mean that physicists would have to go back and reconsider all of nuclear theory to find out where such energies could come from at a blow. How the foundations would tremble!

How could the super-particles themselves settle the matter? Well,

suppose one to have been fired out of the super-catastrophe that created it. In that case, its path would be just about straight, bending very little for the sake of the puny magnetic fields through which it might flash. The direction from which it strikes the counter that detects it would be the direction of the super-castrophe that created it.

If that super-catastrophe is a rare thing that happens only in an exceptional Galaxy, then all the super-particles will come from a few highly specific directions. If, on the other hand, the super-catastrophe is common enough so that it might happen to a small percentage of the stars in any Galaxy, then it should happen to a small percentage of the stars in our own Galaxy. And since the stars of our own Galaxy are so much closer to us than the stars in any other Galaxy, we ought to intercept many more of the super-particles from our own Galaxy than from any other.

But almost all the stars in the Galaxy are in the plane of the Milky Way, and ninety percent of them are in the direction of the Galactic Center (which lies in the constellation Sagittarius). Therefore, almost all the super-particles ought to reach us from the plane of the Milky Way and ninety percent of them ought to come from Sagittarius.

In either case, the theory of energy-formation-at-a-blow would require the super-particles to come from only certain parts of the sky, not all.

On the other hand, if cosmic ray particles begin life as mild creatures of a mere Bev or two of energy and go spiralling around here and there through magnetic fields until they've picked up enough energy to become super-particles, *then,* after all that spiralling, they can end up coming from any direction at all.

So far, preliminary results indicate that the super-particles are indeed coming from all directions, which is the expected but dull answer.

Oh, well, we can't have everything.

These Bev-type particles bring up another point insufficiently discussed in science fiction stories: *i.e.* that it is possible, in all sober truth, to go faster than the speed of light. Now I know I have been saying it isn't, but if you'll look closely, you will see that what I say is that it is impossible to go faster than the speed of light *in a vacuum.* The speed of light *in a vacuum* is about 186,282 miles a second, but in any transparent medium other than a vacuum, light travels at a lesser speed. The particular speed can be obtained by dividing the vacuum speed of light by the index of refraction of the transparent medium under consideration.

By this method, we can prepare a small table:

Substance	Index of Refraction	Speed of Light (miles/second)
Water	1.33	140,000
Quartz	1.46	128,000
Glass (average)	1.7	110,000
Diamond	2.42	77,000
Rutile	2.90	64,400

(In case you're wondering, rutile is a transparent form of titanium dioxide.)

Well, a proton of a mere 75 Mev or so will dash through rutile at a speed greater than that of light passing through rutile. A 10 Bev proton will outstrip light in diamond or glass. The 30 Bev proton of the new Geneva synchrotron will handily outrace light even in water.

When a particle exceeds the speed of light in a particular medium, it throws backward a "wake" of radiation, just as a plane exceeding the speed of sound throws back a wake of sound. The blue-white radiation given off by a faster-than-light particle is called "Cerenkov radiation," after P. A. Cerenkov, the Soviet physicist who first noted it in 1934.

But pumping particles through transparent liquids and solids at velocities greater than that of light in those media is child's play to the modern physicist. What is harder is to do the same in the case of gases. Air, for instance, has an index of refraction which, at sea-level pressures, is equal to 1.0002926. This means that the velocity of light in sea-level air is equal to 186,227 miles a second, which is 55 miles a second less than the speed of light in a vacuum.

A proton moving at a velocity of 186,227 miles a second has an energy of just about 20 Bev, which means that any proton with more energy than that can leave a trail of Cerenkov radiation in air.

Nor is air the prize package. Both hydrogen and helium have indices of refraction lower than that of air; being 1.000132 and 1.000036 respectively. Light therefore travels at speeds of 186,257 miles a second in hydrogen at sea-level pressures and 186,275 miles a second in helium at sea-level pressure.

For a proton to leave Cerenkov radiation in hydrogen, it must have an energy of over 28 Bev; while to do the same in helium, it must have an energy of over 180 Bev. This means that the Geneva synchrotron can manage to produce protons that will leave Cerenkov radiation wakes in air and, just barely, in hydrogen, but not in helium.

Naturally, the super-energetic cosmic ray particles can do better. The 5,000,000,000 Bev particles travel at a velocity that falls only about an inch a minute short of the velocity of light in a perfect vacuum.

In other words, suppose a super-particle and a beam of light start from Alpha Centauri in our direction. Both would have to travel about 25,000,000,000,000 miles to get here and both would take about 4.3 years to do it. The light beam would get here first, but with just a 30-mile lead, which is darned little considering the length of the race-track. The cosmic ray particle would cover that final 30 mile gap in less than one six-thousandth of a second.

If we assume that the index of refraction of hydrogen falls off linearly as the pressure decreases, then a sample of hydrogen rarefied to about a ten-millionth of its sea-level density would be sufficient to slow up light to the point where it travelled only as quickly as a 5,000,000,000 Bev cosmic ray particle.

To any casual inspection, hydrogen gas at such a low density level would be considered a vacuum, but the super-particle would show this wasn't so by the Cerenkov trail it would leave (assuming it could be detected.)

But that's as far as it goes. The density of hydrogen gas in interplanetary space is far rarer still and the best cosmic ray particle ever detected comes nowhere near producing Cerenkov radiation in outer space.

Oh, well; again I say, we can't have everything.

It is clearly time, the Good Doctor indicates, to be on watch for a revolution—but what we most urgently need is a good idea for the kind of revolution we shall have.

FOUR STEPS TO SALVATION

by Isaac Asimov

One of the large questions that must concern the science-fiction devotee is the one that says: "Where do we go from here?" Considering that "here" looks remarkably like a precipice these days, the logical answer isn't a pleasant one. Perhaps we had better change the question to: "Is there anywhere we can go except over the edge?"

One way of tackling this new question is to consider the route over which we've gotten this far. I have a theory that the main value of studying the past is to make it possible to understand the future, and here's one place where I can test it—at least to my own satisfaction.

Man is unique in that he represents the only species for which the question of "going" has any meaning. All other creatures look neither back nor forward, bear no load of the past, have no fear of the future. They live in a timeless world of immediacy.

Of course, a species may "go" somewhere and even give the illusion of purpose in doing so. Some primitive crossopterygian invaded land and had descendants that were eventually amphibians, and some primitive reptile turned scales into hair and eventually had descendants that were mammals. This, however, has nothing to do with the individual. Such changes are slow alterations in response to environmental pressures, blind competition, natural selection and the rest.

Mankind, however, "goes"

somewhere independently of evolutionary change. He migrates from the tropics to the polar regions without growing a pelt of hair; he returns to the undersea world without redeveloping gills. What's more, he is about to tumble into an environment that no other species on earth has ventured into—outer space—and he will do this without seriously altering his physical nature.

Why, of all species, is man able to make "going" an individual affair? Why can he, to a certain extent, choose where he is to "go?"

The obvious answer is that he is intelligent and, while obvious, the answer is also insufficient.

There are intelligent animals that are in no way master of their own fates to any unusual extent. There is no sign of any gradual change in this respect as intelligence increases. The earthworm has no sense of past and future and lives only in immediacy, and the case is the same for the gorilla. Although the gorilla is far closer to man than to the earthworm, in the physical sense, the gap between gorilla and man as far as time-sense is concerned, is far greater than that between gorilla and earthworm.

It seems to me, then, that it is not merely a question of having intelligence but of having *enough* intelligence. Merely to have *nearly* enough intelligence, as in the case of the gorilla, is of no service at all. In fact, the gorilla is an unsuccessful species on its way to extinction, and would be on its way out even without man's expanding economy in Africa.

So we must determine, if we can, at what point "intelligence" became "enough intelligence."

The progenitors of man first developed a brain larger than those of modern great apes nearly a million years ago, and that brain increased in size steadily (and rather quickly, as evolutionary changes go) and by 200,000 years ago, it was getting close to the modern brain in terms of sheer mass. Nevertheless, for ninety percent of his stay on this globe, pre-man was not to be distinguished from other great apes to any remarkable extent. Pre-man had a large brain, a glimmer of understanding, simple tools flaked out of rock—but still held to nothing more than a skulking and precarious life of hiding from the large carnivores.

If, a hundred thousand years ago, Genus Homo had vanished from the earth, an extraterrestrial observer, surveying the course of life's history on our planet, would have had no reason to think of pre-man as potential lord of the earth. Pre-man would probably have seemed to him nothing more than a curious advance toward intelligence which didn't work out. Intelligence still hadn't become *enough* intelligence.

But Genus Homo didn't vanish. Instead, one hundred thousand years ago, there came the turning point which led on to the inevitable establishment of human dominion over the earth. It was the discovery of fire.

Fire kept man warm through the damp, cold night and over the icy frigidity of winter, and this made it possible for man to migrate out of the tropics (to which all other great apes are confined even to this day). Fire made ordinarily coarse and inedible substances both palatable and digestible, so that man's food supply was increased. Fire, moreover, kept other animals at a distance. Since fire increased man's living-space, his food supply and his security, it probably led to the first population explosion, and after that our extraterrestrial observer would have no doubt that man was destined to be the dominant species on the planet. (I call this the "Paleolithic Revolution.")

But why was fire discovered when it was and not before? Was it a fluke? The breaks of the game? Or was it the result of some crucial evolutionary development of the brain?

Nobody knows, of course, but I have a theory and what's the good of this column, if I can't use it to publish my theories?

Consider what we really mean by the "discovery of fire." It can't mean the mere realization that fire exists. Anything that lives and can sense its environment has some realization that fire exists as soon as it encounters a lightning-started forest-fire. And any living creature that can run responds to a forest-fire in the sensible way. It runs like mad.

But with developing intelligence comes developing curiosity and there must have come a stage when curiosity even buried good sense, so that some pre-man was foolish enough to approach the dying remnants of a burned-out area to watch in absorption while flame danced out of a burning twig. Maybe he added another twig to keep it going.

Perhaps, after any number of pre-men had demonstrated this sort of curiosity, one (more daring than the rest) brought a bit of fire into his cave, or to his camp, perceiving the usefulness of light and warmth after sunset and dimly delighted at the fact that an approaching sabertooth may have shied away at the sight of the flame.

But just having the fire in the cave or at the camp site is not the crucial "discovery" either, for after all, fires have the bad habit of dying out and what does one do then? Wait for lightning to strike again and for another forest to burn down? It is difficult to imagine a revolution, of the type that followed the coming of fire, depending upon a phenomenon that

could come to an end at any time in a moment of carelessness.

Clearly, for fire to remain a continuing force, man or pre-man would have to learn how to make fire where no fire existed before; he had to be able to create fire at will. Perhaps, fire had been brought to the camp site any number of times to enlighten a family or a tribe for some days or weeks and then gone out. It would be remembered in the future as a lucky windfall (like Eskimos coming across a stranded whale) and then, after some time, forgotten. This would not be the discovery of fire. Learning to make a fire, however, to ignite one from a cold start, so that fire under human control became a permanent phenomenon, *that* was the discovery of fire.

What was involved in this discovery? It might have been fumblingly discovered by accident that two rocks struck together created a spark that might set fire to dry and powdery wood. Or some prehistoric genius may have noted the heat developed by friction and twirled a pointed stick in a wooden tinder-filled hole.

How it happened doesn't matter. The point is that it did happen and that, on the Stone Age scale of things, it was a piece of complicated technique that had been discovered. It seems to me quite possible that a person who could make fire was a rare individual and that with his death the secret might be lost again—*unless* he could communicate it to others.

We could suppose that he demonstrated the process by actually doing it and that others, watching, caught on. This is possible, if the process is an uncomplicated one, but learning a complicated process just by watching is a slow and inefficient job indeed. Try teaching someone to do something as apparently simple as swinging a golf club with the proper stance by dumb show only and see how quickly you lose your temper.

By dumb show, you can demonstrate the striking together of two rocks to form a spark, but how, by dumb show, can you explain that only certain rocks will do this, and that the rocks must be held just so and that for heaven's sake, man, the tinder has to be soft and spongy and, above all, *dry!*

The crucial discovery was not fire at all, then, but rather the development of adequate communication.

Now, many animals communicate. All sorts of mammals and birds have warning cries and comfort signals and yowls for help. Communication may not even be by modulated sound. Bees are well known now to be able to pass on information on honey sources by dancing about in various ways. But in all cases, these sounds or other signals are limited to things

of fixed and concrete significance.

What is needed is some form of communication which is complex and versatile enough to be made to represent new ideas; even ideas that have no concrete significance. In other words, a form of communication that can represent abstractions. The only form of communication we know of that will meet this requirement is human speech.

The key importance of speech shows up in experiments in which young chimpanzees and human babies are brought up side by side under identical conditions. For a couple of years, the two advance together. In fact, because chimpanzees mature at an earlier age, the chimpanzee is somewhat ahead of the baby. Then something happens, and the chimpanzee falls behind and remains hopelessly behind forever after. The something is that the baby learns to speak, while the chimpanzee does not.

The importance of speech is shown, in a completely different way, in a well-known story from the Bible (Genesis 11) where God, in order to prevent men from building their impious Tower of Babel, is pictured as adopting a simple (and deadly) expedient. God says: "Go to, let us go down, and there confound their language, that they may not understand one another's speech."

He did so and that effectively ended the project.

My theory, then, is that the discovery of fire came only after the development of speech and that it could not have come before. The development of speech, furthermore, could not have come about until the brain had developed to the point where the speech center was sufficiently complex to allow the necessary delicate manipulation of lips, tongue and palate to make speech possible. (The chimpanzee doesn't learn to speak because it can't; the speech centers in its brain aren't sufficiently advanced.)

This is the point of "enough intelligence" in evolutionary terms. It is at the point of the adequate development of the speech center.

Speech, then, is the first step to salvation.

Speech for the first time linked a species in time as well as in space. If space alone is considered, many forms of life herd or band together, even low forms. What can be a tighter and more integrated society than that of the termite hill?

With the development of speech, however, there came a new power. Parents could pass on their experience and painfully garnered wisdom to their children, not only by demonstration, but by explanation. Not only facts but also thoughts and deductions could be passed on. The new generation could begin with that and build upon it.

This meant that knowledge could be accumulated over several generations. By speech man conquered death, for the wisdom of the past lived on and a tribe consisted not only of the living members, but of dead members (in terms of their remembered words) as well.

This meant that a true culture could be developed, for no art, science or school of philosophy can reach a point of any value at all if one must start from scratch and proceed only as far as a single generation can carry matters. Furthermore, the development of any technique over a period of generations must give rise to the thought of "change" or "progress." For the first time individual members of a species can become aware of having come from some place, from their great grandparents discovery of some technique, to their own better development of it. For the first time, the question could conceivably arise: "Where do we go from here?"

I maintain, now, that it was an advance in communication that made the question possible at all, and that the crucial advances made by mankind involved further advances in communication. Wherever some real revolution takes place in man's way of life, the question of communication will be found to underly it.

For instance, after the development of speech and the discovery of fire, advance was slow and for thousands of generations, man lived on in what we would today consider complete savagery. Even the development of true man, Homo sapiens, about 40,000 years ago seemed to make no difference.

Then, quite suddenly, the "Neolithic Revolution" took place. About 8000 B.C., groups of men in the Near East learned to make pottery, to domesticate animals, to build up permanent communities and, most important of all, to develop agriculture.

How did that come about? If my theory is correct, only through a basic advance in communication.

Speech gives rise to oral tradition and it had been estimated that this will carry over for about four generations before it becomes so badly distorted that it forms no reliable guide. This is not to say that oral tradition cannot carry a germ of truth for longer periods. The tale of the Trojan War was kept alive by oral tradition for far more than four generations, but the germ of its truth was buried under bushels of nonsense about gods.

Well, when any form of human activity is so complicated that it takes more than four generations to develop it to the point of making it a profitable undertaking, speech alone is no longer enough. Paleolithic man may frequently have made stumbling gestures in the direction of agriculture only to

have it die out because after a while no one remembered exactly why great-great grandpappy wanted to keep those weeds around the camp-site.

Something is needed past speech, something to make speech permanent and unchanging, something that could be referred to without so much chance of being misled by distortion. In other words, some sort of written code, representing the sounds of speech.

No one is certain when writing was first developed, but it seems certain that no form of human community which we would call "civilized" was ever established without the possession of at least a small and specialized class that could read and write.

I feel that writing was developed in Neolithic times and that it was writing (or at least a primitive form of it) that made possible the development of agriculture and all the consequences of the Neolithic Revolution. Naturally, writing didn't come in all at once to bury oral tradition methodology forever. The importance of the distortions brought in by oral tradition in developing the techniques of agriculture is attested to by the wide variety of fertility rites that sprang up about it.

As writing developed, treatises on mathematics and architecture could be prepared, tax records could be kept, messages could be sent that would knit together governments over large areas. In short, a society complex enough to build cities and establish empires became possible. The very word "civilization" comes from the Latin word for "city."

Writing, then, is the second step to salvation. It turned a savage into a civilized being.

But even with the discovery and utilization of writing, mankind could not be said to have learned to control his environment in our modern sense. The European of 1500 A.D. would not have felt ill at ease in the Egypt of 3000 B.C., once he got used to the difference in language and religion.

In fact, in many ways it seemed that man's development reached an early peak and then began to decline. The Egyptians, about 2500 B.C., built huge pyramids, and no culture for four thousand years afterward could match the sheer magnitude of such an undertaking (with the one exception of the Great Wall of China). The Minoans in Crete built castles with internal plumbing in 1500 B.C. and that was not matched until as recently as three or four generations ago. The Greeks developed an interpretation of the Universe and the Romans a system of law and government that stood as a shining and unapproached example for a thousand years after the fall of Rome.

In fact, the men of the Renais-

sance looked back to the times of Greece and Rome as a golden age to be imitated. Their notion of progress was a return to the past.

But then, after 1500 A.D., a great change took place, the third of the great revolutions of man's history. The first had been the Paleolithic revolution of fire; the second the Neolithic revolution of agriculture and cities; and now there was the third, the Modern revolution of science and industry. A rapid succession of great men from Copernicus to Newton smashed the Greek view of the Universe and laid the foundations for the new scientific view. Then another succession of men from Papin to Watt laid the foundation for the bending of the energy of inanimate nature to the service of man.

Life changed so that the man of 1961 would feel less at home in the Europe of 1500, than the European of 1500 would have felt in Egypt of 3000 B.C.

What happened? Again there must have been a fundamental advance in communication.

Writing is all very well, but it is a slow and painful process. Books are few and can be distorted by mistakes in copying. Only rich men can afford even small libraries and it takes an advanced culture to support even one or two really good libraries—as long as unaided writing is the only means of freezing words on paper.

Under such circumstances, it is easy for a book to be destroyed, for a whole culture to die. When Nineveh was captured in 612 B.C. the library of Asshurbanipal was destroyed and the Assyro-Babylonian culture was dealt a staggering blow. The slower destruction of Babylon through successive futile rebellions against Assyria and, later, Persia, completed the debacle. Only scraps of the culture have been recovered by assiduous digging.

The great libraries of the Greco-Roman world went one by one as Rome weakened and died. The Library at Alexandria was largely destroyed in the fifth century by fanatic monks and what was left was finished off by the invading Arabs in the seventh century.

Even so the complete corpus of Greek knowledge survived for six more centuries in Constantinople. Then came the sack of that city by the crusaders of 1204 and that was destroyed. What we have left now are mere remnants.

About 1450 A.D., however, the art of printing was developed. With printing, knowledge was suddenly made secure. So many copies of even the most unimportant book could be published that any small town today can have a library which can serve as an important repository of human knowledge.

No atomic war which did not succeed in wiping out the human

race entirely could wipe out human knowledge today to the extent that the sack of a single city in 1204 did.

More than that, before the days of printing, an unpopular view was easily suppressed. The Greek philosopher, Democritus, held that matter was atomic in nature, and the Greek philosopher, Aristarchus, held that the earth revolved about the sun. Both views were unpopular and in the small world of scholarship of those days, such thoughts were not followed up and what writings were put out in favor of those views did not survive. We know of Democritus and Aristarchus only through the casual comments of those who disagreed with them.

Once printing was invented, however, matters were different. Copernicus had views very similar to those of Aristarchus and for many years (for safety's sake) he contented himself with circulating a handwritten manuscript of his heliocentric theory. Naturally, nothing much happened. But then he agreed to have a book printed. Copies of that book penetrated everywhere in Europe and *that* was decisive.

Men could be suppressed, silenced, even burned, but books, once they were published in sufficient nmbers, could not be. Galileo was retired by the Inquisition and reduced to silence, but his books were not and not all the power of the Index could keep them from being read.

Furthermore, every scientist who made a discovery rushed into print and copies of his reports flooded every cranny of Europe. Science became a community-sing performance rather than a solo aria, and many brains made light work.

Printing, then, is the third step

to salvation. It turned philsophers into scientists.

And now what? Each revolution carried mankind only so far and then further advance was dependent upon a new basic advance in communication. Furthermore, the time between advances is shrinking. After the coming of man, 900,000 years passed before the development of speech. Then 100,000 years passed before the development of writing. Then 10,000 years passed before the development of printing.

Now 500 years have passed and I think it is time for the fourth step to salvation.

The printing press still functions with blinding speed (more than ever in fact) and scientific lore is poured out by it in a suffocating flood. Knowledge still flashes from one end to the other of the scholarly world—but who is at the receiving end? Actually, it is simply impossible for one man to absorb it all. He can live and work only by shutting his ears resolutely to almost all of it and concentrating only on the splinter that immediately engages his attention.

There is the real precipice mankind is facing. It is not the possibility of nuclear war which can conceivably be avoided by an exercise of good will all round. It is not the consequences of the population explosion which can conceivably be avoided by the exercise of good sense all round.

The precipice is rather this: That the world of science, upon which man's way of life now irrevocably depends, may break down under its own weight; that the time is coming when one scientist will be unable to understand another; that the time is even coming when no scientist can learn enough in a reasonable

lifetime to make significant advances of his own.

Naturally, there are ways of staving off the evil day. More and more effort should be put into recruiting scientists and developing methods of teaching science and of storing information—there are microfilming and punch-cards and computer memories to help.

There is even room for the encouragement of some scientists to make a specialty of being unspecialized; that is to spend their lives learning as much as they can about as many branches of science as possible in order that they might serve as translaters, describing each specialty to men of another specialty, and all specialties to the general public. (Actually, this is the ideal I have in mind for myself, but I am doing it entirely on my own. I would like to see many men specially trained and educated for the purpose.)

Yet I cannot help but feel that all this staving off of the evil day is only that, a staving off. The evil day will yet come unless the fourth step is taken. And, if my theory is correct, the fourth step must be some fundamental advance in communication.

And try as I might, I cannot imagine what the advance can possibly be, except for the development of some method of pouring knowledge directly from one brain to another without the intermediary of books or even speech. A short-circuiting of all three previous steps, in other words, is the only way we can now keep up with the growing complication of knowledge.

But what is the use of advocating telepathy as an answer when telepathy is not within the realm of possibility? Even people who believe that Rhine-type experiments prove the existence of telepaths and telepathy (and I am not one of those who believe) cannot maintain that the telepathy is at any higher level than that involved in being able to guess the correct card a little oftener than random chance would permit.

Perhaps in the eventual course of evolution, the brain might develop a telepathy center sufficiently complex to send and receive "thought waves" just as the development of a speech center a hundred thousand years ago allowed the coming of speech.

But we can't wait for evolution. We stopped waiting a hundred thousand years ago and we can't start again now.

Which leaves me with the original question as to whether there is anywhere we can go except over the edge.

Alas, I can't think of anywhere.

But then I wouldn't have been able to think of printing in 1400, or of writing in 8000 B.C. and I probably wouldn't have been caught dead within half a mile of a twig-on-fire in 100,000 B.C. . . .

Recovering from an astonished—and astonishing—moment of speechlessness, the Good Doctor talks about the abolition of distinctions. The more it changes, in short, the more it's one thing.

DETHRONEMENT

by Isaac Asimov

NATURALLY, A CONSCIENTIOUS PROFESSIONAL TRIES TO KEEP UP with his field, so when nobody is looking I abandon my lofty role as universal authority and secretly read up on things. (I trust all my Gentle Readers will keep this confidential.)

Among the things I try to keep up with is a periodical called *Science,* which is published weekly by the *American Association for the Advancement of Science.* For those of you who have never seen it, it is a very respectable and learned journal dealing with matters of current interest in science written by and for professional scientists.

There are leading articles (two or three) rather more detailed and technical than those in *Scientific American,* but perhaps less detailed and technical than those in the more specialized learned journals. There are also about half a dozen short reports describing research work in progress. There is a department called "Science in the News," which usually deals mostly with political developments having to do with scientific research; and, in addition, an excellent department given over to book reviews.

It's very worthwhile leafing through *Science* for matters of interest, and every issue will hold something that is worth a thorough reading by any professional. You can understand that I was confirmed in this

view to a point of almost monomaniac intensity when, over the space of the last half year, two of my books were reviewed in the columns of *Science* in so favorable a fashion that I distinctly heard beautiful violin music in the background as I read them.

I am going to have to overcome my natural modesty (which is something I have to do all the time and which, I must admit, is a very easy thing to do) and talk about one of the reviews, because it is involved with this month's column.

The review is that of my two-volume book, THE INTELLIGENT MAN'S GUIDE TO SCIENCE. The review appeared in the 16 December 1960 issue of *Science* on page 1830. (That's not a misprint. *Science* numbers its pages continuously through 26 issues.)

It begins with, "Here, at last, is something new in popular science writing . . ."; says some other nice things; then, down about the middle of the review, it says: "For him (me, that is, I.A.) . . . biology is a system that proceeds from biochemistry to the associated subjects of neurophysiology and genetics. All else, as they used to say of the nonphysical sciences, is stamp collecting."

Now mind you, this is the reviewer talking (who happens, by the way, to be Professor Derek J. de Solla Price, a historian of science, of considerable reputation, at Yale University) and not myself.

He has analyzed my views correctly, to be sure, but I did not myself, anywhere in the book, openly dismiss such branches of biology as cannot yet be brought down to the physical science level, as "stamp collecting." What I did do, however, in view of the fact that I had only a quarter of a million words in which to discuss all of science through all of history, was to select only those topics which I felt were of greatest interest and significance. I left out completely (and on purpose) traditional biology. I suppose that in itself was fairly insulting to the traditional biologist. Had I but known the repercussions.

However, half a year after the review, I picked up the 2 June 1961 issue when it arrived and disposed myself in my armchair to leaf through it leisurely and to select material for careful reading later.

On page 1745, there began a lead article entitled "In Defense of Biology," by Professor Barry Commoner, who is a plant physiologist at Washington University in St. Louis. He was the retiring vice-president of the *American Association for the Advancement of Science* and on 27 December 1960, he gave his farewell address at the annual meetings sponsored by that organization. (I had a chance to attend but chickened out because of the inconvenience of travelling during the Christmas-New Year period. Had I but known—)

This article was a reprint of that address.

I glanced at the first few paragraphs and was wondering whether I ought to read it thoroughly, when I caught my own name in print. (I'm good at that. I have trained myself to pick out my own name at a glance in a solidly packed page of microscopic print. It comes from reading letter columns in sf magazines.)

Naturally, that settled my mind. I went back to the beginning and read the article with an intensity beyond imagining and it turned out that Professor Commoner was tipping his lance in defense of biology against *me.* That realization left me in the condition that the Kindly Editor has been waiting for, lo, these many years—i.e. momentarily speechless.

Apparently what roused Professor Commoner's ire particularly was the reviewer's crack about "stamp-collecting." Having quoted that with disapproval he went on to select a sentence that was actually in my book and pounded away at that. It was the sentence that opened the second volume and it goes:

"Modern science has all but wiped out the borderline between life and none-life."

To this, Professor Commoner took violent exception. He went on, immediately after quoting my sentence, to say (and these are his words):

"Since biology is the science of life, any successful obliteration of the distinction between living things and other forms of matter ends forever the usefulness of biology as a separate science. If the foregoing sentence is even remotely correct, biology is not only under attack; it has been annihilated."

He goes on further to say that I base my remark concerning the vanishing distinction between life and non-life on the theory that all life processes are dependent on the functioning of nucleic acids and that I maintain that this functioning, although terribly complex, follows the ordinary laws of chemistry and physics. In this, Professor Commoner interprets me correctly.

However, he takes an opposite stand and elaborates a point of view which I can boil down to the following quotation from his article, one which he labels as his "chief argument." It goes:

"Analysis of living systems, based on modern physical and chemical theory, leads to the conclusion that life is unique and that it cannot be reduced to the property of a single substance or of a system less complex than a living cell."

Now I have written to *Science* offering to rebut and they may or may not accept my offer, but that scarcely matters. This column is

my favorite soap-box anyway, and one upon which I can speak freely.

Let me begin then by saying that politics and economics are not the only fields in which conservatism is to be found. There are conservatives in science, too—but they usually lose out and therefore make less of a mark upon history. And, very often, despite their profession, their defense of the past is based more on emotion than upon reason.

Consider, for instance, that Professor Commoner feels that if it is true, as I say, that the distinction between life and non-life is being wiped out, then that "ends forever the usefulness of biology as a separate science . . . it has been annihilated."

With all possible respect, I can only ask: Is this a rational view?

Let's consider. There was a time when the universe was considered as consisting of two grand divisions, the earth and the heavens. Each was distinct, each was unique, each followed separate laws. Earth was corrupt and changing; heaven was perfect and unchangeable. Earth was motionless; heaven and all it contained moved in grand circles.

Yet even with this view it was possible for men to study the nature and constitution of the earth and it was also possible for them to arrive at results we would consider valid. The Greeks, for instance, worked out the size and shape of the earth quite accurately.

Nothing much further than this was done because of the primitive state of science generally, but more could have been done. The earth's mass could have been determined without reference to the heavens (as it was, indeed, eventually determined). Earthquakes could be studied and the earth's internal structure conjectured upon. Oceans could have been plumbed. The atmosphere could have been analyzed.

Without reference to the heavens at all, geology could have become a science of respectable accomplishments.

Suppose this had actually happened and that then, in the time of Copernicus, in 1543, the heliocentric theory had been announced. The earth, it would turn out, was just a planet and one of a number of planets, revolving about the sun just as Mars and Venus did.

Would there then arise a howl from the geologists?

Would they say: This ends the distinction between the earth and the other planets. It ends forever the usefulness of geology as a separate science. Geology has been annihilated.

Well, would *this* be reasonable?

Of course it would not, because the facts are quite the contrary. The study of the earth is made all the more meaningful by the fact that the earth is not unique among the objects of the universe.

At no time in history, in fact, have geologist and geology been as

important as they are now. This is not *despite* the fact that space studies have grown so glamorous and popular, but *because* of it. The Mohole project, for instance (see "Recipe for a Planet," F&SF, July 1961) is important not just because the information it gathers will be of use to geologists, but because that information will be of use to astronomers as well.[1] To wipe out the distinction between geology and astronomy is to make each one more important.

I see no earthly reason, then (aside from emotional upset), to consider biology annihilated, if the distinction between life and non-life vanishes. Rather, its importance will be heightened when physicists and chemists come to realize that biology's deepest insights will be of direct service to them.

Science is a unit, and if it seems broken up into arbitrary divisions that is the fault of the age of intellectual over-specialization in which we live. Scientists who labor to make the partitions between the divisions inpenetrable and insurmountable are doing science a great disservice.

And what about Professor Commoner's "chief argument," the one in which he claims that life is unique and that it cannot be the property of anything less complex than a living cell?

This in itself actually represents a great advance in thinking, for it was only a century and a third ago that the cell theory was advanced and that cells were maintained to be the unit of life. Before that time, it was felt that life could not be the property of anything less complex than a living organism intact enough to include the essential organs. I have a feeling that Professor Commoner would have strenuously supported that view against the new cell-theory notion, had he lived in 1840.

Now, without going into technical details and without in any way attempting to match Professor Commoner's intensive knowledge of biology, I can only say that I am certain that life *is* a function (a highly complex one, to be sure) of a molecule and not of the cell, that life is *not* uniquely different from non-life, and that the distinction between life and non-life *is* disappearing.

My reasons are based not upon the actual detailed discoveries of the moment, but upon a consideration of the whole history of science. They are based not upon where we are but upon where we are going.

I have mentioned Copernicus's development of his heliocentric theory,

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[1] If you want to read up on Mohole, I strongly recommend A HOLE IN THE BOTTOM OF THE SEA, by Willard Bascom (Doubleday, 1961)

for instance; his notion that the earth is but a planet like other planets, circling the sun as the others do.

What is that but the dethronement of the earth? From a highly special position as center of the universe and as the only motionless body within it, it suddenly found itself lost in the shuffle, a body like other bodies.

Look upon it in this fashion and the history of science becomes the long story of repeated dethronements, one after another.

Thus, when Copernicus dethroned the earth, he left the sun as a new unique body. *It* was the center of the universe, *it* was the one motionless body. If earth was not unique, it at least revolved about a sun that was.

That did not last either. Eighteenth century astronomers gradually accepted the notion that stars were suns, and that our sun was by no means the only body of its sort in the universe.

In the nineteenth century the distance of the nearer stars was determined, as were the sizes and motions of those stars. Our sun was found to be not motionless after all, and it was dethroned in that respect. Beginning with the astronomer, William Herschel, the sun began to be considered part of a galaxy, one of many millions of stars, moving about in vast circles about some unimaginably distant center. What's more, the sun was but an average star in every respect. Yet it retained a last scrap of its uniqueness, for it still seemed to be just about in the center of the Galaxy.

Then, in the 1920's, newer techniques were used for probing the Galaxy (see "The Flickering Yardstick," F&SF, March 1960) and it turned out that the sun was not in the center but far toward one end. Furthermore, there was not one galaxy, but millions upon millions of them.

Our galaxy, at least, seemed for a while to be unique, for it was larger by far (so it seemed) than any other. Then, in the 1940's, a new scale of distances was worked out and our galaxy sank into ordinariness.

We are now living on an ordinary planet circling an ordinary star that forms part of an ordinary galaxy. Astronomical dethronement has been complete.

To the Greeks, the laws of motion existed in two forms. On earth, objects moved in a number of odd ways and motion always stopped. In the heavens, bodies moved only in grand circles and combinations of circles and motion never stopped.

Copernicus and Kepler described heavenly motions in a more useful

way than did the Greeks, and Kepler, in particular, showed that heavenly motion was not circular.

Galileo, about 1590, worked out the laws governing motion on earth, founded the science of mechanics, and showed motion on earth was not irregular but followed set and simple laws.

But it was Newton, in 1683, who made the grand synthesis. He took Galileo's new science of mechanics, organized it, presented it to the world with masterly simplicity and clarity and showed that the same set of laws could be used to explain not only the motions of bodies on earth, but also the motion of the heavenly bodies. The same laws applied to earthly mechanics and to celestial mechanics. (And this did not annihilate the study of ballistics—it made it more important.)

Nor was this the only distinction abolished between heaven and earth. In 1860, the spectroscope was invented and soon thereafter applied to the heavens. It turned out that the sun and the stars were made up of precisely the same elements of which the earth was composed. In the one legitimate case in which an element was discovered in the heavens that was not known on earth, it was discovered on earth thereafter (see "The Element of Perfection," F&SF, November, 1960).

Even up to the 1930's, the existence of the Solar system, at least was considered as possibly unique, even if neither earth nor sun was unique separately. Solar systems originated, it was thought, in the collision or near-collision of two stars, and such accidents were so exceptional that ours might well be one of only half a dozen planetary systems in all the Universe.

No one believes that anymore. They may not quite know what to believe instead, but they don't believe *that*. It seems quite certain now that whatever the details of the process by which the planets were born, it was a process that involved the sun alone and did not require the interference of any colliding body. Whatever influence the rest of the universe had (in the form of gravitational force or radiation pressure, say) was exerted from a distance.

Planetary systems are now considered the rule and our Solar system is anything but exceptional. It, too, has been dethroned.

And aside from astronomy?

Chemistry has made all matter, so infinitely varying in appearance, consist of several dozen different types of atoms. Nuclear physics has made all atoms consist of a considerably smaller number of sub-atomic particles. The distinction between particles of matter and blobs of radiation has been blurred since, in the 1920's, particles were shown to behave like waves and waves like particles.

Even if we don't get down to very fundamentals, distinctions are blurred and uniqueness is dethroned. For many years, chemists felt that all chemical substances could be divided into two groups: organic (originally formed by living organisms) and inorganic (everything else). The two seemed subject to different set of laws and it was widely held that organic substances could not be formed from inorganic. Some sort of "life force" was required that was not at the disposal of the laboratory worker.

Then, in 1828, Friedrich Wohler *did* form an organic substance (urea) from an inorganic substance (ammonium cyanate) and within a few years, many other organic substances were formed from the inorganic world. The organic substance was dethroned—its uniqueness had begun to crumble.

In 1857, William Perkin synthesized the first artificial dye and by 1900, thousands upon thousands of organic substances that did not exist in nature had been formed. Man was not only imitating the "life force," he was improving upon it. The dethronement was complete.

Of course, man was synthesizing only relatively small molecules. What about giant molecules, like those of the proteins? Living cells could bring about all sorts of reactions very quickly and under very mild conditions, which the lab man could not bring about at all, or, at best, under strenuous conditions and then inefficiently. The cellular ability was due to the presence of special protein molecules called enzymes within the cell.

In the 1890's, it was felt that only within the cell could those enzymes work. For biochemists then, like Professor Commoner today, felt that as soon as you got below the level of the cell, you had left "life" behind.

Then, in 1897, Eduard Buchner ground up yeast cells and filtered the juice and found that this juice (quite without cells and quite "dead") fermented sugar as well and as efficiently as the living cells could. The distinction between cells and non-cells blurred.

And in the 1950's biochemists began to learn to synthesize the more simple protein molecules and the synthetic product has all the properties (including the effect on the body) of the natural one.

But life itself? Well, here we have one great 19th century advance that seemed to work in the opposite direction, in that of enthronement. Louis Pasteur, in 1860, finally established the impossibility of spontaneous generation. Life could only arise from previously existing life and not from dead matter. This seemed to establish the uniqueness of life.

It is important, however, to remember *exactly* what Pasteur proved. He showed that life could not develop from non-living matter in the space of a few weeks under the particular conditions he used, the present atmosphere, for instance, and the present solar radiation.

But what if a different atmosphere were involved, and a different type of solar radiation and the whole ocean was the reaction flask with a billion years or so for the reaction to take place? In theory, the non-living matter of the primordial ocean, bathed in the rays of the primordial sun and saturated with the gases of the primordial atmosphere would, after a long interval, develop life. In fact, experimental methods have indicated that the very first steps in the process might indeed take place as theory indicates.

Scientists feel reasonably certain that on any planet similar to earth (and there are many millions such in the universe, they now feel sure) life would eventually exist.

Not only is the distinction between life and non-life blurred in this respect but the earth is, in all likelihood, dethroned from its unique position as a life-bearing world—even, perhaps, from its unique position as an intelligence-bearing world.

Nor need life be entirely a product of proteins and nucleic acids (see "Not As We Know It," F&SF, September, 1960). The protein molecule and even the carbon atoms may yet be dethroned from their unique connection with life.

And what about man?

In 1859, Charles Darwin advanced his theory of evolution, in which, for the first time, rational and, indeed, inescapable arguments were presented to show that one species changed into another, that life itself was one grand unrolling ("evolution" means "unrolling" in Latin) of unified life into greater and greater variety under the lash of the blind and random forces of natural selection.

In particular, fossils of "pre-men" have been discovered, since the 1890's, through which man loses himself and melts into a complete lack of distinction from other species.

The "species" was dethroned as the unit of life-form. Man himself was dethroned as a creature unique and different from all other forms of life.

To many non-scientists (and even to some scientists) the successful obliteration of the distinction between man and other animals, at least on the physical level, threatened to end forever the usefulness of religion. Religion to them seemed threatened with annihilation.

Their fears were, of course, groundless (as Professor Commoner's

fears are today). Religion survived and, in its essentials, it was strengthened, for I don't know how one can argue that religion can be weakened by being freed of dependence upon a false view of the material world.

Now, then, with scientific advance moving always in this one direction of dethronement . . . in this one direction of obliteration of distinction and of removal of uniqueness . . . in this one direction of making a single set of laws, a single viewpoint, cover widely disparate phenomena . . . in this one direction toward culmination in a grand and beautiful simplicity—what are the odds that, suddenly, life will turn out to be unique, that, suddenly, there will remain a distinction forever established between "life" and "non-life."

Surely, the odds must be prohibitively high against that.

I predict, with great confidence, that more and more of the properties of the phenomenon that we think of as "life" will be interpreted on the basis of generalizations which apply also to systems we think of as "non-life." I predict that mankind will be able to construct systems that will be considered "non-life" but that will, more and more, seem to duplicate properties of what we consider "life." The distinction between "life" and "non-life" *will* vanish.

In fact, I also see the end of a further distinction, for to me there seems no essential, vital and insurmountable difference between the human brain and the computer. The computer, complex enough, will be indistinguishable from a brain. And so the last distinction will be blurred, that of "mind" and "non-mind."

Nor does that last blurring seem distressing to me. If a mechanical mind is ever devised that is equal to the mind of a man, then we have a machine that *is* a man. And if we build one that is better than a man, then he is a superman and should replace us on this planet.

Let me quote from my book THE INTELLIGENT MAN'S GUIDE TO SCIENCE a passage which Professor Commoner does not quote in his article, but which I feel he may consider more outrageous than any that he did quote. It is to be found on page 745, and it reads:

"What achievement could be grander than the creation of an object that surpasses the creator? How could we consummate the victory of intelligence over Nature more gloriously than by passing on our heritage in triumph to a greater intelligence—of our own making?"

SCIENCE

In which Dr. Asimov—with some slight assistance from another savant—argues that We Are Not (to put it mildly) Alone.

WHO'S OUT THERE?

by Isaac Asimov

PROFESSOR CARL SAGAN (PRONOUNCED SAY'GUN) IS THAT PARAGON of scientists; one who occasionally interests himself in problems of peculiar fascination to the science fiction community and one who occasionally sends reprints of his papers to me. I have already written one article (BY JOVE, May 1962) based directly on one of his astronomical papers.

Consequently, when I learned that he was returning from his stint at Stanford University in California and was going to take up his position in the astronomy department at Harvard University, nothing would do but I must meet him. I called him, therefore, and we set up a luncheon date. The result was that I enjoyed a most pleasant luncheon and was rewarded with a number of interesting items.

One in particular was an advance copy of a paper entitled "Direct Contact Among Galactic Civilizations by Relativistic Interstellar Spaceflight" and you can tell from the title that this is something right up our alley. As I write, it is about to be published in a learned journal and some non-learned journals (such as *Life*) are expressing interest.

It seemed to me, however, that the contents of the article must not be allowed to remain buried in places such as *Life* but must be given the wider circulation (among those who really count, that is) guaranteed in the pages of this magazine.*

** I must warn you that my report on Professor Sagan's paper occasionally contains ideas of my own which I do not always carefully distinguish from those of the professor. He must, therefore, on no account be held responsible for anything foolish I may happen to say.*

To begin with, Sagan estimates the number of technically advanced civilizations (advanced enough to be capable of interstellar communication) now existing in the Galaxy. This is a favorite sport among astronomers these days (and even among nonastronomers such as myself) but this is the first time I have seen the details of the calculation given so clearly and in such detail.

Note, though, that the problem is to determine the number of such civilizations *now existing;* a civilization that existed in the past and is now extinct does us no good. To find out how many exist now, one must calculate how many originate per year and multiply that by the number of years each endures (on the average). If, just to take random figures, ten civilizations are formed each year and each lasts a thousand years, then (working strictly "on the average") there are ten thousand such civilizations now extant; ten of them one year old, ten two years old, ten three years old; and so on up to ten that are a thousand years old and about to be extinct. Each year ten new ones would be born and ten old ones die so that the number would stay at ten thousand.

The first problem, then, is to estimate how many technologically advanced civilizations are formed per year. We begin by considering the number of stars formed per year, since we can expect no civilizations in the total absence of stars.

The total number of stars in the Galaxy is estimated at 100,000,000,000 and the age of the Galaxy is about 10,000,000,000 years. This means that stars have been forming in the Galaxy at an average rate of ten per year. Of course, the rate of formation has very likely not been average at all times. At the present moment, the best estimate is that stars are being formed at the rate of only one per year, and, presumably, in the early days of the Galaxy they were being formed at a very rapid rate. Dr. Sagan, however, after some discussion feels it fair enough to keep to the average. Therefore we begin with the fundamental estimate that:

$$\text{Number of stars formed per year} = 10$$

But technically advanced civilizations do not develop upon stars, but upon planets revolving about those stars. The next step, then, is to estimate how many of the stars coming to birth are attended, then or ever, by planetary systems.

It turns out that there are two kinds of stars, those that rotate rapidly and those (like our Sun) that rotate slowly. The ones that rotate slowly

are believed to do so because most of their angular momentum has been shifted outward to the planetary bodies. This is the case most certainly, for instance, with our Sun. Fully 98 % of the angular momentum of the Solar system is possessed by the planets; only 2 % by the Sun.

About 98 percent of the stars, it so happens, belong to those spectral classes associated with slow rotation, so we can conclude that just about every star is attended by a family of planets. Consequently:

Number of planetary systems
formed per year = 10

As we all realize, however, technical civilizations cannot be expected to develop on all planets indiscriminately. They won't develop unless a particular planet is of a type on which life (as we know it) can develop. Such planets should, as a minimum, be at a temperature where water (or some equivalent substance) may exist in form appropriate for the reactions of life. The temperature must never fall so low at any time in its orbit that all water is frozen, or rise so high that all water is vaporized—using water as the most natural example of a life medium.

It is supposed that where a planet revolves about a star belonging to a multiple system, such a temperature requirement cannot be met. The orbit is erratic enough to put any such planet into the too cold class or the too hot class periodically.

The number of stars that are members of multiple systems include about half of all stars. That leaves only the remaining half as possible illuminators of livable worlds. These consist of the lone-wolf stars (like our Sun) and we must ask ourselves how many planets suitable for life each of these lone-wolves possesses.

The only planetary system we can study in detail is our own and here we can make the following statements. One planet (the Earth) is definitely the abode of life. One planet (Mars) is, as far as we know, suitable for life as we know it and may even possess such life. There are reasons for arguing that life is conceivable on other planets as well but Sagan prefers to be conservative. Taking our own planetary system as typical (and we have no reason to think it is anything but typical) we can say that, on the average, each lone-wolf star possesses two planets capable of supporting life.

Since the lone-wolf stars represent half the total number of stars in the Galaxy and since carries two livable planets, the total number of livable planets is equal to the total number of stars:

Number of livable planets
formed per year = 10

However, a technical civilization will not develop upon a planet capable of supporting life unless life does, in fact, develop upon it. The next step, then, is to estimate how frequently life develops on a livable planet.

Based on modern notions, it would seem that if a planet possessed the proper composition (approximately that of the primitive Earth or of the present Jovian planets) and the proper temperature, then the development of life is almost inevitable.* In our own Solar system, there are two Earth-type planets, Earth and Mars, and, indeed, life has developed on one and has, quite possibly, developed on the other as well. This is particularly impressive since Mars is only borderline Earth-type, and if life has developed on it then it ought certainly develop on any planet more closely approximating Earth conditions.

So we assume that every livable planet does, in fact, develop life and:

Number of life-systems
formed per year = 10

But life in and of itself is insufficient for a technical civilization. One must have intelligent life and here matters grow rather shaky. There is no way of estimating how often intelligence develops. Let us say that life has existed on Earth for 1,000,000,000 years and that reasonably intelligent man-like creatures have existed for 1,000,000 years. Both figures are reasonable and in that case, intelligence has existed during 0.1 percent of the history of life. Or, to put it another way, through 99.9 percent of life's history, intelligence did not exist and was, apparently, not missed.

There is no painful stretching of the imagination required to suppose that even if intelligence had not developed, life would have continued happily onward forever after. Might not intelligence be the result of an extremely lucky accident; so lucky that it is never likely to be duplicated in the course of the evolution of any other life-system?

Arguing against that is this: the evolutionary trend has been more or less constantly in favor of increased complexity and, in particular, of increased complexity of the nervous system. This makes sense since the more complex the nervous system, the more keenly an organism is

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* *I'm saving this bit for another article someday, but take my word for it now.*

aware of its environment and the more versatile is its fashion of responding—and both factors are of prime survival value. It seems fair to suppose that a similar trend will exist in other life-system evolutionary processes.

But if the nervous system continually increases in complexity then the development of intelligence is inevitable and, as a matter of fact, it may well have happened twice on Earth and not just once, for it is becoming more and more likely that certain cetaceans (dolphins and the like) are intelligent and are only debarred from unmistakeably showing it by the fact that they live in the sea and lack manipulative organs.

Consequently, we conclude that the development of intelligence is not fortuitous but, given enough time, inevitable. So next we ask what is "enough time?" Looking at it astronomically, intelligence developed on Earth at a time when the Sun was five billion years old, or only midway through its livable period. What's more, most stars are smaller than the Sun and have longer livable periods. There is no reason to suppose then that the time available is not "enough." Just about every life system ought to have enough time at its disposal to evolve intelligence.

Nevertheless, in order to pamper his own conservatism, Sagan estimates that only one life-system in ten will do so. Therefore:

Number of intelligent life-forms
formed per year = 1

But even intelligence, in and of itself, is insufficient. We are trying to estimate the number of *technologically advanced* civilizations, and it is possible that an intelligent life form may never develop such a civilization. The dolphins never did and in all likelihood never will do so of themselves. Even mankind doesn't have a very good record if you consider the following:

Mankind has existed at a level of intelligence higher than that of the ape for at least 1,000,000 years, but how long has he been civilized?

The word "civilized" comes from the Latin word for "city" so that literally we are asking how long mankind has been a city-dweller. This is a good way of putting it for only with the development of agriculture could man stay in one place long enough to build a city and only with agriculture could he be assured of a food supply large enough to make it possible for him to divert enough of his energies to build one. Certainly the combination of agriculture and cities is a minimum requirement for what we usually think of as civilization.

Well, the oldest cities are roughly 10,000 years old so that we can say that mankind has been civilized for only 1 percent of the time it has been intelligent. To put it another way: for 99 percent of the history of human intelligence, men have been savages everywhere. Even when civilization did develop, it involved, at first, only a small minority of mankind and spread outward among the savage majority but slowly. (In fact, the outward spread is not complete even now, ten thousand years after the beginnings of civilization.)

Furthermore, through much of the history of civilization, its basis has been non-technological in that the sources of the energy applied to the works of civilization were mainly that of animal muscle (including the human, of course). The energy of wind and water were used, but only in minor fashion. It is only in modern times that the energy of inanimate nature was put to work on a large scale.

This dates back to the invention of a practical steam engine in 1769. Man has possessed a technologically advanced civilization, then, for only about 200 years. In other words, for 99.98 percent of the time in which reasonably intelligent men roamed the Earth, no technological civilization worthy of the name existed. And when such a civilization developed, it did so in only a small section of the civilized world.

Finally, it is only in the last couple of decades that man's civilization became sufficiently advanced technologically to permit of interstellar communication and of a reasonable hope for eventual interstellar travel.

Can we then say that even where intelligent life develops, the chance of technological civilization is so small that it may be ignored and that we may forget the whole thing?

No, for as in the case of the development of intelligence it is possible to argue that we have witnessed an inevitable development. During man's million years of existence, he did not stand still. His brain underwent an almost explosive increase in size and it is only toward the very end of the period that the modern brain in its modern proportions was finally developed. Homo sapiens himself has only been dominant some forty thousand of years.

Once Homo sapiens ("modern man") came into being, civilization followed almost at once (evolutionarily speaking). Furthermore, it developed in several different places independently to prove that it was no accident. Even if we allow the civilizations of Sumaria, Egypt, Anatolia, and the Indus to be branches arising from a common source; there are still the civilizations arising in China, in the Yucatan and in Peru, all of them necessarily independent of each other.

Technology developed only once, and that was in northwestern Europe. We will never know whether it could have developed elsewhere independently, since technology diffused outward from its single source so rapidly as to drown out any possible independent start elsewhere. However, a technological civilization almost developed during the great days of Alexandria two thousand years ago (but didn't for reasons we need not discuss here).

Consequently, we can assume that intelligent life will be inevitably followed by a technological civilization and that such a civilization moves toward interstellar travel with explosive speed. Once again, however, to be conservative, Professor Sagan assumes that only one out of ten intelligences will establish a technological civilization. This means:

Number of technological civilizations
formed per year = 1/10

Or, if you want to put it another way: Every ten years (on the average) another technological civilization capable of interstellar exploration originates in our Galaxy.

There's the first part of the problem solved (or at least estimated). With a technological civilization formed every ten years, it remains to determine the average duration of such a civilization in order to work out the number that exist at the present moment.

But what is the duration of such a civilization? If we consider ourselves (the only technological civilization we know) then it is conceivable that we may destroy it tomorrow, even before interstellar travel becomes possible. At least two men in the world can do this any time by giving the order to press some buttons. Perhaps every civilization that gets technological enough destroys itself in fairly short order by misuse of nuclear or other power. In that case, the average duration of such a society may be very short, say 100 years.

On the other hand, we may be a poor example. Perhaps civilizations ordinarily develop without quite the nationalistic fervors and hatreds we have and survive the nuclear danger. They may then utilize their mastery over the inanimate environment to keep their civilization going for eons, let us say, for 100,000,000 years. Perhaps even we poor Earthlings will hang on to sanity long enough to do this.

If we take the pessimistic view, then, the total number of such civilizations now existing is 1/10 (the number formed each year)

multiplied by 100 (the average number of years of duration), or 10. And the number may be even smaller than that. On the other hand, if we take the optimistic view then the total number now existing is 1/10 times 100,000,000 or 10,000,000. And the number may be even greater than that.

Professor Sagan reaches between these extremes and believes that same technological civilizations survive for extended periods. He feels that it is reasonable to suppose that:

Number of technological civilizations
now existing = 1,000,000

If this is so, then one star out of every hundred thousand carries such a civilization, and we can start to speculate further as to the distance by which such civilizations are separated and, in particular, how far away the nearest civilization may be from us.

Well, I have seen it stated that the average separation of stars in the neighborhood of the Sun (that is, in the spiral arms of the Galaxy) is about 9.2 light years. If only 1 star out of 100,000 is inhabited by a technological civilization then that average separation must be multiplied by the cube root of 100,000, which comes out to about 46.5. If we multiply 9.2 by 46.5 and round off the result, we may estimate that the most probable distance between ourselves and the next technological civilization is about 400 light years, or ten times the distance of Arcturus. (Professor Sagan commits himself only to "several hundred light-years.")

Dr. Sagan goes on to analyze the possibilities of practical interstellar space travel. This I will not touch upon because, with my usual frugality, I will save it for another article some time. His conclusion, however, is that interstellar space travel, while difficult and expensive, is possible.

He assumes that such travel will result in contacts between civilizations and in cooperative ventures that will make it possible to pool all the results of Galactic exploration teams and thus increase the efficiency of the ventures. (I would like to point out myself that such a combined Galactic civilization would be more stable and enduring than would any of the individual members.)

Professor Sagan suggests that each civilization can launch enough interstellar exploratory vessels to effect one contact with another planet per year. This means that there are a total number of contacts,

over the Galaxy as a whole, of 1,000,000 per year and that the number of starships on patrol required to make this feasible is between 1,000 and 10,000 at any one time.

If there are 1,000,000 contacts per year and 100,000,000,000 stars in the Galaxy altogether then, assuming contacts to be made on a purely random basis, each star is visited by a starship once every 100,000 years. If this has been going on at this rate over the billion years or so during which life has existed on Earth, then it may be that our own Solar system has been explored 10,000 times in that interval. Earth's history may be recorded in considerable detail in some Galactic archive far, far away.

But contacts need not be made in a random manner. Once intelligence develops on a planet, the curiosity of the starships may well be roused to the point where contact is made every 10,000 years and once a technological civilization is established, every 1,000 years.

In that case, they may have been 100 contacts in the history of man, and it is conceivable that the last one may have been at the dawn of civilization. Sagan considers the possibility that some human myths may refer not to gods but to extra-terrestrials (and how many times this has been considered in science fiction I hesitate to estimate) but decides that the interlarding of the supernatural is such that almost no conclusions can be drawn.

However, he goes on to say: "As one example [deserving further study], we may mention the Babylonian account of the origin of Sumerian civilization by the *Apkallu*, representatives of an advanced, nonhuman and possibly extraterrestrial society."

I myself have never heard of the Apkallu, but Sagan's reference is to "E. R. Hodges, 'Cory's Ancient Fragments,' revised edition, London: Reeves and Turner, 1876; P. Schnabel, 'Berossos und die Babylonisch-Hellenistische Literature,' Teubner, Leipzig, 1923."

I suggest that it would be a fine piece of research for some Gentle Reader to look up these formidable sources and see what details concerning the Apkallu he can find out. (No, I will not do it myself.)

Professor Sagan suggests that it is even conceivable that the starships have established some sort of automatically-maintained base in the Solar system. This would have to be near the Earth which (with all due modesty) must be their prime center of interest in the Solar system, but not on the Earth where atmospheric weathering and human tampering is to be expected. To be near the Earth but not on it makes it seem that the base might be somewhere on the Moon—one more reason to explore our satellite thoroughly.

Sagan concludes by suggesting that within several centuries we may be due for another contact and says: "Hopefully, there will then still be a thriving terrestrial civilization to greet the visitors from the far distant stars."

I would like to add just a little bit to all this. Professor Sagan deals only with our own Galaxy, but what about other galaxies?

It is usually estimated that there are at least 100,000,000,000 galaxies in the known universe. Some of them, to be sure, are actively emitting radio-waves for a variety of catastrophic reasons (several have been advanced—and I am reserving them for a future article) and perhaps such fouled-up galaxies are not very rich in life-forms.

But if we estimate that 10 percent of the galaxies are "radio-rich" and "life-poor," that still leaves us with 10,000,000,000 galaxies, each with 1,000,000 technologically advanced civilizations.

This would mean that in the known universe there would be some 10,000,000,000,000,000 (ten quadrillion) civilizations at our level or better. There would be over three million races of beings as good as ourselves or better for every man, woman and child on earth, if they were parcelled out evenly.

There is something to puncture human self-esteem if it were puncturable!

SCIENCE

ISAAC ASIMOV

AT THE EDGE

ON THE day I am writing this paragraph, my dear wife, Janet, and I have been married sixteen years. It's a tribute to her that she enjoys the situation, for my sense of humor is not only irrepressible, but also intolerable.

I'll give you an example. When Janet is going out to shop or to do some other neighborhood errand, she offers to mail my letters for me. I hesitate, because I have spent a long lifetime in which I have been full of reluctance to let anyone else do things that I can only trust myself to do. If someone else offers to mail my letters — what if they forget, or carelessly throw them down a sewer, or accidentally eat them, or who knows what?

Janet is, of course, annoyed at my evident distrust and makes it very clear that she considers herself as intelligent and trustworthy as I am, and that my letters are as safe in her hands as in mine. It becomes clear, in fact, that if I insult her by refusing to let her mail them there will be marital earthquakes of the most pronounced sort. So I let her have the mail with a fixed and nervous smile.

Then, when she comes back, I cannot prevent myself from asking, diffidently, "Did you remember to mail my letters?"

Sometimes she glares at me, and sometimes she sighs dramatically, but in either case she answers, "Yes, I did." (And I must admit that every letter she has ever offered to mail for me has reached its destination.)

One day, recently, she returned from her errand, having taken with her a sizable handful of my letters, and called out, in a firm tone of voice, before I could say anything, "Yes, I *did*."

I stared at her mildly and said, "Well, thank you — but aside from that, dear, did you mail my letters?"

I was running a great risk, but fortunately she broke out laughing.

On another occasion, Janet and I were in a taxi which had stopped for a red light. A man on the curb, who may have had too much to drink (or who may, possibly, have known a good thing when he saw it), called out to me, "I want your wife."

To which I replied agreeably, "Fine with me, sir. She's all yours," and the taxi took off.

"So," said Janet, "you're anxious to give me away!"

"Not at all, dear," I said. "That was just my little joke. I would *never* give you away to *anyone*" (Pause) "Of course, if someone were to offer me an adequate sum —"

And she burst into laughter again.

It's harder to laugh, however, when it is the Universe that seems to be having a joke, and a bunch of hard-working scientists are left with egg on their face. Take, for instance, the case of the missing planet at the edge of the Solar system.

There were five star-like planets known from the earliest days of civilization. I say "star-like," because the Sun and Moon were also considered planets till the sixteenth century, and then they were dropped from the list. At the same time, Earth itself was recognized as a planet.

The five star-like planets, then (plus Earth, included in parentheses), are, in order of distance from the Sun: Mercury, Venus, (Earth), Mars, Jupiter and Saturn.

The reason the star-like planets were noticed in those earliest days was, first, because they are bright. They are as bright as, or brighter than, the brightest stars in the sky.

The planets are distinguished from equally bright non-planet stars because the stars retain their positions relative to each other unchanged, year after year, century after century. (Not quite, but close enough so that the ancients didn't notice any changes.)

The bright planets, on the other hand, moved relative to the stars generally and to each other, and did so unmistakeably. They changed position from night to night.

That made it easy to assume that the five star-like planets were all there were. If, after all, there were other planets, they would have long since been easily seen and recognized by their brightness and their motion.

The assumption was wrong. The farther a planet, the dimmer it is likely to be, and the more slowly it is likely to move. Thus, of the known planets, Saturn moves most slowly, and it was taken for granted because of this (and correctly so) that it was the farthest of the planets. Saturn was also dimmer

than the other planets, though still bright, and, therefore, not as obtrusive as any of the others except Mercury (which is difficult to see, not because it is so dim, but because it is usually quite close to the Sun).

If, then, in addition to the six planets (counting Earth), there was a seventh planet, farther than Saturn, it would be dimmer than Saturn and would move more slowly, and for these two reasons it would be harder to notice. In addition, the sky is full of myriads of stars. If the stars are arranged in levels of decreasing brightness (or increasing dimness) then at each level, there would be more stars.

Thus, there are only 20 stars that are bright enough to be considered first magnitude, but there are several thousand stars that are at the lower levels of brightness and appear very dim to the unaided eyes.

There *is* a seventh planet, which we now call Uranus, but it is twice as far from the Sun as Saturn is and is smaller than Saturn besides. It is so dim that it has a magnitude of 5.5, which makes it visible to the unaided eye but not by much, and it is lost among some four thousand stars that are at the same level of visibility. What's more, since Uranus moves against the background of the stars more slowly than any of the other planets, that motion is the more likely to be overlooked.

Consequently, it was not till 1781 that Uranus was discovered, and then by accident. What's more, it took some time to get it through astronomers' heads that it was really a planet, and not a comet (see THE COMET THAT WASN'T, F & SF, November 1976).

Once Uranus was discovered and its orbit was plotted, it turned out, as decade after decade passed, that it didn't follow the exact path indicated by Newton's theory of gravitation.

It would, if the Sun were the only body that controlled Uranus's motion. The large planets, Jupiter and Saturn, however, also added tiny "perturbations," and these had to be taken into account in plotting Uranus's actual orbit. Every effort was made to calculate the exact mass of Jupiter and Saturn, and just how their distances from Uranus changed as all three bodies moved along their separate paths around the Sun.

However, even with masses and distances all nailed down as surely as possible, Uranus's motion still drifted slightly out of true. Some astronomers therefore concluded that there must be another sizable planet somewhere beyond Uranus, an eighth planet that was exerting a gravitational pull that hadn't been

taken into account.

A British astronomer, John Couch Adams (1819-1892), and a French astronomer, Urbain Jean Joseph Leverrier (1811-1877), independently worked on that problem. Beginning with the deviations of Uranus in its orbital motion, they made several reasonable assumptions as to the size and orbit of the possible eighth planet and calculated where in the sky it would have to be at the moment to account for the deviations. Both came out with approximately the same answer, Adams being first by about eight months.

But now came the catch. Neither Adams nor Leverrier had direct access to a good telescope, and they had to persuade the head of some important observatory to make the necessary search. Easier said than done. Astronomers were reluctant to do so and we can see their point.

The new planet would be considerably dimmer than Uranus and would be surrounded not by thousands of stars of equal dimness but by tens of thousands of them. What's more, the new planet would move more slowly than Uranus and would be easier to miss. And it might not even be there. Naturally, astronomers were reluctant to waste valuable telescope time.

Leverrier, however, had a break. He asked a German astronomer, Johann Gottfried Galle (1812-1910) of the Berlin Observatory, to make the search. Galle went to the head of the observatory, Johann Franz Encke (1791-1865), to ask permission. Encke was celebrating his birthday and wasn't going to be using his telescope. He therefore let Galle have it for that one night, and Galle got the help of a graduate student named Heinrich Ludwig D'Arrest (1822-1875).

Fortunately for the two, they searched the archives and came across a new star map of considerable excellence that covered the precise area of the sky within which the planet was predicted by Leverrier to exist. Using the star map, they found the eighth planet, which was later named Neptune, in the first hour of the search and rushed over to Encke's birthday party to give him a *real* present.

Neptune was of magnitude 7.8; it couldn't be seen without a telescope, but it was there (see THE SEA-GREEN PLANET, F & SF, December 1976).

Neptune accounted for 98 percent of the error in Uranus's motion, but that left 2 percent unaccounted for. Naturally, it was possible to suppose that there was still another planet beyond Neptune, a ninth, that also pulled at Uranus but more weakly.

However, very few astronomers

were really interested in the matter. Calculating the position of an ultra-distant planet from the ultra-tiny errors in Uranus's motion would take incredible mathematical exertions. Then, even if they were to locate a likely spot for its existence, what would the search be like? The ninth planet would be considerably dimmer than Neptune, would move more slowly and would be lost among not tens of thousands, but *millions* of stars of similar brightness. And it might not be there. It would take a madman to tackle the job.

However, a madman was on the scene. He was the American astronomer Percival Lowell (1855-1916), who devoted the last fourteen years of his life to making the necesary calculations and carrying through the necessary search. He found nothing, but long after his death, the search still continued. In 1930, the American astronomer Clyde William Tombaugh (b. 1906) found the ninth planet, Pluto, quite close to the spot predicted by Lowell (see DISCOVERY BY BLINK, F & SF, January 1977).

That seemed to take care of everything — but it didn't. Pluto was dimmer than Lowell had expected. Indeed, it was far too dim, and the suspicion grew that it was a small planet. Indeed, as more and more was learned about Pluto, it turned out to seem smaller and smaller (see THE INCREDIBLE SHRINKING PLANET, F & SF, March 1987). We now know that it is only 1420 miles across, only about two-thirds the size of our Moon in diameter and only 1/6 our Moon's mass. Considering that it never approaches more closely than a billion miles to Uranus, it is unbelievable that Pluto's tiny mass could have any measurable effect on Uranus's motion. Our own Moon would have as great an effect on Uranus as Pluto would have.

This means that the "residual" errors of Uranus's motions cannot be explained by the existence of Pluto. The fact that Pluto was found more or less where Lowell said it ought to be found was just coincidence.

Doesn't that mean that there must be *another* unknown planet, a *tenth* planet? If so, it would have to be larger than Pluto, or closer to Uranus or Neptune, or both, if it were to have the necessary effect on the outer planets. But in that case, if Pluto were found, why not the tenth planet as well?

As it happens, Tombaugh, after he had discovered Pluto in 1930, went on to use his technique to see what else he could find. He spent years and years studying photographs of the sky to see if he could find any other planet. He made use

of a blink comparator, which compared two photographs of the same region of the sky taken several days apart. Each photograph was cast on a screen in rapid alteration and, while the stars did not move as the focus went from one photograph to the other, a planet would have moved relative to the stars in the interval, and it would blink back and forth.

By 1943, Tombaugh had examined 45 million stars. In the process, he had found some novel astronomical objects far outside the Solar system. Inside the Solar system, he discovered a new comet and no fewer than 775 asteroids that hadn't been seen before. However, he found no new planet.

If there had been a tenth planet the size of Neptune, Tombaugh ought to have spotted it even if it had been 12 times as far away as Pluto's average distance from the Sun.

Tombaugh finally decided that there were simply no planets in existence that were large enough or close enough to Uranus to account for the errors in Uranus's orbit.

And yet — And yet —

It would be so easy for weary eyes to miss the blink. Tombaugh quit the search because he simply couldn't stand it any more, and there may have been a long period before he quit where it was just impossible for him to give it the necessary concentration. Maybe the tenth planet was there all right, but he hadn't seen it — and no one else has made that kind of thorough study.

Besides, it's not just the trifling errors in Uranus's orbit. There are things much more spectacularly wrong out at the edge of the planetary system. From Mars to Uranus, each planet seems to be roughly twice as far from the Sun as the one that is next innermost. (You have to count the asteroid Ceres to make this work.) Neptune, however, is not twice the distance of Uranus from the Sun, but only one and a half times more distant.

Then, too, Neptune's sizable satellite, Triton, goes about Neptune in retrograde fashion, moving from east to west. All the other sizable satellites and many of the smaller ones move about their planets in direct fashion, from west to east.

That's not all. Pluto has a most unusual orbit. It is tipped, by a considerable amount, to the general plane in which all the other planets orbit the Sun. Thus, a model of the Solar system out to Neptune would fit in a pizza box very nicely, but Pluto's orbit would carry it up above the pizza box at one end and down below it at the other. What's more, Pluto's orbit is lopsided so that at

one end of its orbit it is twice as far from the Sun as Neptune is, while at the other end (where it happens to be right now) it is actually closer to the Sun than Neptune is.

Finally, it turns out that Pluto has a satellite, Charon, that was discovered in 1978 by the American astronomer James Christie.

This is *very* unusual. Pluto is by far the smallest object in the Solar system that is known to have a still smaller body circling it. After Pluto, the smallest such object is Mars, which has a mass 50 times as great as Pluto, and which has two tiny satellites, each much smaller than Charon.

Indeed, Charon has a mass that is 1/10 that of Pluto, and no other object in the Solar system has anything that large (compared to itself) circling it. Pluto is a fair approximation of a "double planet." The next nearest approach to a double planet is the Earth/Moon system, but the Moon is only 1/81 the mass of Earth. Other satellites are smaller still compared to the objects they circle. If Jupiter itself is considered the largest "satellite" of the Sun, the mass of Jupiter is only 1/1000 that of the Sun.

So here are the mysteries:

1) Why is Neptune so close to the Sun?

2) Why does Triton circle Neptune the wrong way?

3) Why does Pluto have such a tilted and lopsided orbit?

4) Why does Pluto have such a comparatively large satellite?

Some astronomers have thought that there must have been some sort of catastrophe at the outer edge of the planetary system. Pluto, they think, may once have been a satellite of Neptune, and something had happened to hurl it out into an independent, but cock-eyed, orbit. A second satellite may have ended up as Charon; or else Pluto, in the stress of whatever it was that kicked it out, may have broken in two.

And whatever it was may have reversed Triton's motion and perhaps driven Neptune closer to the Sun.

But what could have happened? It couldn't have involved Neptune, Triton, Pluto and Charon only. Some sizable outside body with a significant gravitational pull must have been involved. In short, the tenth planet.

The easiest supposition, perhaps, is that there is another planet out Pluto way, one that is larger than Pluto, and that its existence has simply been missed, and that Pluto, the smaller of the two, has just happened to be discovered by lucky circumstance.

One astronomer, calculating from the tiny errors in Uranus's orbit, suggests that the tenth planet

is about 1/3 the mass of the Earth, which would still make it about 170 times the mass of Pluto. Its orbit would be a bit closer to the Sun than Pluto's is, and it, too, would approach the Sun more closely than Neptune does at one end of its orbit. Still another astronomer suggests a planet that is still larger, that is about half the mass of the Earth, and bit farther out than Pluto.

Either version of the tenth planet would explain the errors in Uranus's orbit, but whether such planets are large enough to involve Neptune in an early catastrophe seems doubtful. After all, Neptune would have about 30 to 45 times the mass of such Pluto-like planets. Besides, all calculations that would tend to locate such planets have not resulted in their being found. They should be more easily spotted than Pluto, but they have not been seen.

A more radical suggestion is that the tenth planet is a giant, not as large as the four known giants, to be sure, but still large. Some astronomers have proposed a tenth planet that is 4 to 6 times the mass of Earth and therefore a quarter to two-fifths the mass of Neptune. Surely so large a planet should be seen far more easily than Pluto has, but it has not been seen at all.

There is a possible explanation for that. It may be that this large tenth planet has a very lopsided and tilted orbit (one that is much more lopsided and tilted than that of Pluto). At its farthest, it might be two or three times as far away as Pluto and might be dim enough to miss, especially since it would be far outside the general plane of planetary orbital motions, and, outside the plane, astronomers wouldn't be looking carefully.

At its closest to the Sun, this large tenth planet might be close enough to Neptune for its gravitational pull to be significant. It might take a thousand years to circle the Sun, and since Neptune is moving also, it might take even longer for it to get reasonably close to Neptune. Once long ago, it did come reasonably close, and in the mixup and imbroglio, Pluto and Charon were kicked out, Triton's motion was reversed, and who knows what might have happened to Neptune. If Neptune were kicked closer to the Sun, the tenth planet may have been kicked outward. Perhaps, some centuries from now, the tenth planet will come close enough to the known edge of the planetary system to be seen.

Of course, we don't have to search the sky with telescopes only. We have other devices now, namely, probes.

At least two planetary probes have reached the edge of the planet-

ary system and are penetrating beyond. They are Pioneer 10 and Pioneer 11, and they have left the Solar system in almost opposite directions.

The position of these probes can be determined by the radio signals they send out, and their orbits can thus be described. Every planet they pass has had a strong influence on their orbit, and, at various distances, further tiny influences are added.

It is possible to take into account the gravitational pull of all the planets, knowing their masses and their changing distance from the probes. (To do this we now have computers, which earlier astronomers did not have.) If the probes do not follow the path exactly, once all the gravitational influences are added in, then there must be another gravitational influence, presumably that of the tenth planet, that is not being allowed for.

As a matter of fact, however, the orbits of the probes show no deviation and display not the slightest tendency to respond to some unaccounted-for gravitational influence.

This would seem to indicate there is no tenth planet, but the argument is not airtight. If there is a tenth planet with a very outrageous orbit, it may now be in a part of its orbit so far from the Pioneer probes as to have no measurable effect upon them. Of course, Voyager 1 and Voyager 2 are in the process of leaving the Solar system on still other paths. Their orbits will also be studied.

At the start of this essay, however, I said that sometimes the Universe has its joke. Where does the joke come in?

The joke arises out of the fact that the extremely successful flight of Voyager 2 carried it past Uranus in January 1986, and past Neptune in August, 1989.

In order to direct Voyager 2 accurately, the rocketmen at the Jet Propulsion Laboratory had to know exactly how Uranus and Neptune were moving and exactly where they would be when the probe passed. It turned out that the calculations were very good. Uranus and Neptune were right where they were supposed to be when Voyager 2 passed by.

But why was that? Why weren't the slight errors in the orbits of Uranus and Neptune sufficient to cause Voyager 2 to miss the planets by a substantial margin and to spoil the experiment? The answer was that there were no such slight errors.

The JPL people used only sightings and careful observations of Uranus and Neptune that had taken place since 1910 and ignored everything prior to that year. The fact is

that telescopes and techniques are much better in the 20th Century than they had been in the 19th, and all those supposed errors in Uranus's orbit may have been the artifact of 19th Century inaccuracy.

Astronomers would in that case have been searching for a tenth planet to explain something that didn't really exist. Isn't that a kind of a joke on the part of the Universe (if you haven't been one of those that devoted considerable time to searches for a tenth planet)?

But maybe it's not a joke after all. In the first place, the search did uncover Pluto and Charon, which might not have been discovered for many years otherwise. In the second place, we might still have a large planet with a lopsided orbit that is now so far away it is not affecting Uranus and Neptune. Perhaps it was closer to the edge of the system in the 19th Century, and it did affect those planets then. And perhaps some centuries from now it will move in and be detectable again.

After all, we still need a tenth planet to account for the outer-edge catastrophe.

Meanwhile, astronomical instruments continue to improve. Computer-driven radio telescopes can already locate astronomical objects with far greater accuracy than ordinary optical telescopes can. The outer planets have strong magnetic fields that can be observed but they are widely spread out so that they can be located only fuzzily. However, suppose a probe is placed in orbit around Uranus and Neptune, and suppose that this probe is the source of a radio pulse that is different from those produced naturally by the planets and is easily distinguishable from them.

The radio pulse of the probe would be essentially a point source and, by locating it as it circles the planet, the planet's center could be located to within a few dozen miles. Considering that the outer planets are 1 or 2 billion miles from us, a few dozen miles represents an amazing pinpointing process.

If the motions of Uranus and Neptune are followed in this manner, even tiny deviations from the theoretical can be detected with great accuracy, and the effect of a tenth planet might be noted and its possible position worked out. We'll have to wait and see.

NOTE: I don't generally recommend books on the subjects I discuss in these essays. Every once in a while, however, I read a book that is so good, so pleasant, so useful and helpful, that I really feel I ought to mention it to the readers. The book in this case is PLANETS BEYOND. It is by Mark Littman and was published by John Wiley & Sons in 1988. Highly recommended.

SCIENCE

ISAAC ASIMOV

THE GREATEST CONQUEST

I HAVE JUST had a very bad month. For the first time in 52 years (!) I came down with the flu. I had long considered myself immune to it, but it finally bit me. Naturally, I was totally indignant at the ignominy of it.

As flu cases go, mine was mild — a low, short-lived fever, and none of the coughing and aches and pains that are supposed to accompany the disease. I could scarcely tell I had it.

Except for one thing. I had an overpowering sense of weakness, so that I spent weeks and weeks sleeping, or staring stupidly at the ceiling, or crawling to the bathroom.

Do you know — can you imagine — how humiliating that was and how miserable it made me? In my 51 years of literary endeavor, I had scheduled my writing tasks and set up my deadlines with the calm assurance that I would never be too sick to work every day all day. Heck, I even worked on the three occasions when I was hospitalized, though I admit I goofed off on the actual days of my operations.

But suddenly to be helpless for nearly a month! To barely be able to keep up with my mail and with my regular columns that simply had to be done even if I were dying! It was unbearable.

I'm recovered now but I'll never get over having lost a month.*

And then — do you want to hear the cherry that topped the sundae? Last Friday I went to the hospital, over my loud objections, to take "one more test." I had been there two days before for chest x-rays, echo-cardiograms, and the stealing of about six gallons of my blood, but they wanted "one more test."

It was a test that I knew would reveal nothing I didn't already know, and I said so, and I turned

* *Alas, it turned out not to be flu, but congestive heart failure. And I lost three months, not one. I apologize to one and all. I am in normal shape again.*

out to be right, but go talk to doctors.

So I went.

As it happens, the hospital has killer elevators. The up-down indicators don't work. Sometimes they say up when they mean down, sometimes down when they mean up, sometimes both are signalled at once, and sometimes neither.

Therefore, whenever the elevator stops, the people waiting yell desperately, "Going up? Going down?" The people on the elevator invariably seem confused and have to plunge into thought to decide where they're going, and by the time they have it straight, the doors close. Also, the elevators don't necessarily stop at a floor just because you've signalled for it. They have minds of their own and go where they please.

Finally, when the elevator door closes, it doesn't do so tentatively, you can bet. It slams shut with a savage clang. (After all, the hospital is dealing with old people, with tired people, with sick people, with frightened people — why give them gentle elevators?)

In any case, I decided on one occasion that the elevator was going up, and I started to get in and the elevator closed on me, struck me when I was off balance and sent me flying, base over apex, so that I came down hard on my left hip.

I was at once dragged to the nearest doctor who ordered a left hip x-ray and found that I hadn't broken anything. (Lucky for them. Had I broken my hip I was in the mood for a law-suit. A big one.) So I went home and recovered, but suffered several days of pain that I absolutely didn't need. I don't go to a hospital in order to be assaulted with intent to destroy.

Now that I've told you all this, has it anything to do with the subject I'm going to discuss this month? Not a thing! I have gotten some fury off my chest and I am now going to discuss something as far away from the flu and from the medical profession as I can manage.

Let us consider the Earth as it was 450 million years ago or so. For one thing, it was swarming with life.

We don't know exactly how that life got started, but I'll tell you one thing — it wasn't hard. It couldn't be. The earth was less than a billion years old when primitive bacteria-like cells began to swarm in the sea. And part of that first billion years had to be spent collecting all the sizable bodies in Earth's orbit, withstanding the rain of destruction (including a possible collision with a Mars-sized body that led to the formation of the Moon) and then cooling down and gaining sufficient

stability to be a possible home for life.

It's my feeling that life formed just about as soon as it could, so that it must have been a very natural development.

The seas and waters of the Earth generally continued to be full of life for billions of years, and slowly and gradually (though at an increasing rate) that life grew more complex. By 450 million years ago, the oceans had all the kinds of creatures we are now accustomed to find there, up to and including fish.

There was, however, no life on land.

Life formed in the sea, as easy as flip your wrist, but it did not form on land. Life developed in the sea and became more complex, but it did not form on land. Four hundred fifty million years ago, Earth was 90 percent of its present age, and life in the sea was incredibly ancient, but there was still no life on the land.

Why not?

Well, think about it. The ocean is made for life. Temperature variations over day and night, over winter and summer, over glacial and interglacial epochs, don't change very much. There is always water present, and almost always ample oxygen (after photosynthesis had been developed). There is lots of food present, too, and gravity is of no account because the buoyancy of water upholds life-forms.

It is possible for a 150-ton blue whale, the largest animal that has ever existed on Earth, to move freely through the oceans, unhampered by its colossal weight.

In the ocean, too, there is protection against harsh radiation from the Sun. A relatively thin layer of water will do the job.

Compare this with what would face life if it were to emerge on land. It would be subject to extremes of temperature such as it would never have found in the gentle sea. It would be exposed to the direct light of the Sun. It would have a problem of how to keep from losing water, drying out, and dying. It would have to fight the ever-present pull of gravity, which would be dragging it down, dragging it down. And it couldn't collect oxygen neatly out of water solution, but would have to gulp it out of dry air.

Looked at this way, it is no mystery that for 90 percent of the existence of the Earth, the dry land remained sterile. The real mystery is why it didn't stay sterile to this very moment. Why should any life forms have eventually made their way out onto dry land? What was there on dry land that could possibly entice them?

The answer, to my way of think-

ing, was security. The seas were full, competition was terrific, life was short.

If, however, a life-form could move out onto dry land, it would find space, solitude, and an absence of predators. That's something.

For billions of years, the tides had been pushing the water up the sloping beaches and down again. Life forms were carried with the water. There was always the chance of being stranded, and life-forms that were stranded died.

However, what if, eventually, life grew complex enough so that an appropriate mutation might enable a life-form to endure the absence of water for just a bit longer than it would ordinarily be able to. It might be able to hang on till the next wave came and brought it back. I haven't the faintest idea exactly what the mutation would be; nor, I imagine, has anyone else, but it can't have been a very likely one, or it would have happened long before it did.

Little by little, as mutations piled up, life-forms might have found it possible to exist on the shore for longer and longer periods without the need of water immersion. These life-forms could not be animals, of course, for there would be nothing to eat on the sterile land. Even if they could hold out on dry land for a while, hunger would send them pushing back toward the water.

Plant life, on the other hand, doesn't need food in the ordinary sense of the term. It makes use of sunlight, plus carbon dioxide in the air (of which there was plenty 450 million years ago), plus the water that soaks the beach and, of course, the dissolved minerals in that water. What they needed, in addition, was some waterproof outer surface that would keep them from drying out in the comparatively waterless surroundings.

The first known plants capable of living on land had no roots and consisted of a simple forked stem without leaves. They did, however, possess a vascular system — that is, ducts for the transmission of water and dissolved minerals. They made their timid appearance at the edge of the shore about 450 million years ago.

With time, they developed stiffening agents that would enable them to grow upright despite the pull of gravity, and to spread parts of themselves outward to catch the sunlight they required. They had to develop roots that would hold them firmly in the ground and would absorb water and dissolved minerals from the soil.

Of course, over the course of millions of years, plants did that.

Picture the Earth as it was

between 450 million and 400 million years ago, as the dry land turned green, and as the green spread slowly, but inexorably, along the course of rivers and into well-watered plains.

It was in a way a Garden of Eden for the plant world since for those 50 million years they were free of animal infestation. (To be sure, once animal infestation started, life schemes were evolved that made the animals useful, and even essential, to the plants.) We must also remember that the plant world competed among itself quite fiercely, if silently, growing higher, sending their roots deeper, spreading their leaves wider, always in the attempt to get more of the good things of life than its neighbors would.

Eventually, before the 50-million-year period was over, plants had become trees, and the dry land was covered with forests for the first time.

Do you see what that meant? For the first time in the history of the Earth, fire could exist. As long as the dry land was sterile, there could be no fire. Lightning existed, to be sure, and the bolts struck everywhere but ignited nothing. What was there to burn? The sea was full of life, and the living things in it were rich in carbon and hydrogen and were, therefore, inflammable — but not for as long as they remained in the sea. (Perhaps petroleum deposits on land, developed from the decay of countless life-forms in the sea, might be ignited by lightning, but that must have been rare indeed.)

The forests on dry land, however, which had built themselves up primarily of carbon and hydrogen atoms and which had discharged excess oxygen atoms into the atmosphere, finally set the stage. A lightning stroke hitting a forest tree could start a wild fire, so frightening and destructive. (It's hard to think that something as common as fire existed on Earth only in the last tenth of its existence.)

Plants could not occupy the dry land on their own forever. They represented food and, clearly, any animals that could somehow work out the necessary mutations to survive on land would have all the food they could eat.

Not easy. Plants could develop stiffening agents and become trees because they didn't have to move. Their "food" was all about them. Animals on the other hand, had to search about and find food. It wouldn't come to them. (To be sure, clams and oysters in the ocean could afford to remain motionless and allow water currents to bring them food, but the dry land isn't

quite that user-friendly.)

This meant that animals were faced with the problem of moving about, despite the force of gravity exerted upon them. One way of diminishing the importance of gravity is to remain small. The smaller an organism is, the smaller the gravitational pull upon it, and the easier it is to operate despite the existence of that pull.

By 400 million years ago, some forms of animal life had developed the necessary mutations that made it possible for them to survive on land. All were invertebrate. All were small. The first to crawl out on dry land and to begin to feed on plant life were such life-forms as spiders, scorpions, snails, and worms. Some 370 million years ago, primitive insects appeared on land. Insects could even achieve the ultimate mobility of flight through the air — the first creatures to develop the three-dimensional life in air, the kind of life that was so commonplace in water. However, they were able to do it only because they were tiny.

To this day, land invertebrates are small. In the ocean, there are giant squid and giant clams, large lobsters and crabs, but on land, there are only occasional invertebrate specimens that are as much as a few inches across. For the most part, they are tiny. Gravity defeats them.

If we are to have *large* land creatures, then we need a stiffening material that doesn't interfere with mobility. That means an efficient internal structure of bone to which strong muscles can be attached. I don't say that that is the only conceivable way of handling the problem, but it is the only way that biological evolution has so far developed.

There were indeed bony creatures — vertebrates — in existence. They were filling the sea at the time the land was being colonized by animals. They were the fishes, who were the dominant life-form in the sea, then, as they are now.

The most successful group of fish, at the present time, are the "Actinopterygii" ("ray fins," because the fins consist of skin stiffened by horny rays). Ray fins first appeared about 390 million years ago. A second group of fish, the "Sarcopterygii" ("flesh fins") also developed. Their fins consisted of a lobe of flesh and bone, fringed with the skin and rays of an ordinary fin.

Both types of fish seem to have started in shallow water, and to have developed simple sacs into which they could gulp air from which they could absorb oxygen. Such sacs supplemented the action of gills and helped out if the shallow

water turned brackish and muddy. They amounted to primitive lungs.

The ray fins were better adapted to sea life. They moved into the deep ocean, where the gills worked adequately and the air sac became something used only for buoyancy. There the ray fins were so successful that none of them have ever made a true advance into land life (though we hear of catfish that can stump about on land for a way).

The flesh-fins remained in shallow water, kept their lungs, and lost out in the evolutionary sweepstakes. They declined in number and variety, and few of them survive today. Nevertheless, they persisted long enough to do something marvelous.

One type of flesh-fins was the "Crossopterygians" ("fringe-fins"), who had a particularly interesting arrangement of bones in their fleshy fins, an arrangement that resembled those now found in modern land vertebrates.

Presumably, these fringe-fins could stump around on land on these sturdy little "legs" of theirs, and this came in handy. If the pond they lived in was growing too brackish or was drying and becoming too small, they could make their way overland to a larger pond, gulping air in their primitive lungs as they did so.

Naturally, as time went on, varieties developed that were more efficient at this, that could stay out of the water for longer periods, that could withstand the horrible dry-land conditions more easily.

And at some point, a fringe-fin ceased being a fish and became what we call an "amphibian." There's probably no sharp division really; these classifications are strictly human-made.

The earliest creatures that biologists are willing to call amphibian date back some 370 million years. They were the first sizable land animals to exist, the first to be able to fight gravity, not by being small, but by managing to move about (not very efficiently, to be sure) on bone-reinforced legs.

For some tens of millions of years, amphibia were the dominant life-form on land. Some species were armored and grew quite large. The largest known amphibian was "Eogyrinus" ("dawn tadpole," though it looked far more like an alligator than like a tadpole). It grew to a length of some 15 feet.

The amphibia, however, in their turn lost out in the evolutionary sweepstakes. The large amphibia declined and became extinct. By that time, amphibia of the modern type were evolving, who found survival value not in size and armor, but in smallness and obscurity. Modern amphibia are small animals

generally — frogs, toads, salamanders. The largest amphibian species now alive is the Chinese giant salamander, which may attain lengths of three feet or a little more.

What was it that caused the amphibian failure? One of the reasons, for sure, was that they were not true land animals. They were more or less tied to the water.

Even when an amphibian in its adult stage can remain permanently out of water, there is bound to come a time when it must lay eggs, and those eggs must be laid in water. What's more, what comes out of the egg is a fish-like creature that gradually repeats the evolutionary procedure of adapting to land.

We are best acquainted with this where frogs are concerned. The eggs, deposited in water, hatch into tadpoles, little fishlike objects with gills and fins, which only gradually develop lungs and legs, and emerge on land. In fact, the very word "amphibian" means "double-life."

(To be sure, some modern amphibia have developed very ingenious methods of hatching their eggs without actually depositing them in bodies of water, but these are simply refinements of the model and not anything truly new.)

Apparently, this tie to the water is a weakness, for when a creature developed that was truly independent of water from birth to death (except for the necessity of getting enough of it to avoid dehydration) then it replaced the amphibia.

The successors were the "reptiles" ("creepers," so-called because the best-known modern reptiles are the snakes.)

What did the reptiles do? They made the greatest invention in the whole history of land life, that's all. They inherited the land as a result, and they and their somewhat modified descendants still rule it today.

The great invention of the reptiles was a protected egg, capable of being laid on land. The egg was surrounded by a shell, that was permeable to air but not to water. Oxygen could reach the developing embryo inside, carbon dioxide could be given off, but water could neither enter nor leave.

The egg is laid with a supply of water ample for the needs of the embryo till it is ready to emerge from the egg. The egg also contains an elaborate system of membranes within which wastes can be stored. One of these membranes is the "amnion." It is the most intimate of the membranes, directly enclosing the embryo.

Any life-form that lays an egg with an amnion is an "amniote." All reptiles, and all animals that have descended from reptiles, are amniotes. (Let's face it. You and I are amniotes.) The amniotes are the

only true land vertebrates and have dominated Earth's land surface for well over 300 million years. In fact, in December 1989, it was reported that a reptile fossil had been discovered that seemed to be 338 million years old. If so, it is the oldest reptile and, therefore, the oldest amniote so far detected.

Naturally, we don't know the details whereby the amniote egg was formed. It could scarcely have happened overnight with a snap of the fingers. There must have been primitive amniotic eggs, capable of standing a little dehydration, but not too much, so that, in the course of time —

But what an invention. In my opinion, it was the greatest conquest that life made, for it meant that the dry land could be thoroughly colonized, that large vertebrates could move everywhere and were not condemned to remain near the presence of open bodies of water.

The reptiles, with their amniotic eggs, multiplied, diversified, and filled the land. They were really large. Some of them were the largest and most magnificent land creatures that ever lived. And while they ruled, no other forms of life had a chance.

We're used to thinking of birds and mammals as dominant forms of life now, but that's strictly the result of accident. The first birds developed about 140 million years ago, as slightly modified reptiles.

They were warm-blooded (as, just possibly, some of the reptiles were), and they developed the unique structures we call feathers to preserve the heat.

They survived by being small and unnoticeable and, also, by continuing to lay amniote eggs, so that they lived by the wonderful reptilian invention.

Mammals?

Well, early on in the development of the reptiles, a group of "theriodonts" ("beast-teeth") evolved. They developed mammal-like traits. They had skeletons that were quite mammalian in character, and they may even have developed warm-bloodedness and hair, though we can't tell that for sure from the fossil remains.

These "mammal-like reptiles" were, however, failures. They were mostly extinct by 170 million years ago, while the dinosaurs, thoroughly reptilian, were flourishing and triumphant.

The theriodonts didn't *entirely* die, however. Some species survived that were very small and were even more mammalian than the theriodonts themselves. In fact, they *were* mammals.

They first appeared about 200 million years ago, and they were extremely primitive and small,

being the size of mice and shrews. In fact, the only reason they survived was that they were largely unnoticeable to the magnificent rulers of the land and because, in all probability, they multiplied at an extraordinary rate of speed.

These early mammals, you must remember, were egg-layers, like the duckbill platypus and the spiny echidna today, and the eggs they laid were, of course, amniote eggs. So though mammals were warm-blooded and had hair to conserve their warmth, they were, in fact, only slightly modified reptiles, their life made possible by the reptile-invented amniotic egg.

It was not till about 70 million years ago that mammals developed the placenta and made the first important new advance in embryonic birth since the advent of the reptiles. (The egg they produced was still amniote to begin with, however.) Even after the first placental mammals appeared, they were still small and obscure, still mouse-sized, still practicing survival through unnoticeability.

And thus it would have continued to this very day, I firmly believe. You and I would not be here, but somewhere out there newer forms of dinosaurs would be clumping, some perhaps having evolved in surprising ways we can't possibly guess at.

Except for what happened 65 million years ago.

At that time, Earth apparently suffered an impact, cometary or asteroidal, that created such havoc that there was a "Great Dying." We can't really explain why some species died out and some survived, but it certainly seems as though the large species (fewer in number and requiring more food per individual) were more vulnerable than the smaller ones.

The dinosaurs all died out, along with other giant reptiles, though some reptiles survived. Many of the small birds and mammals also survived.

When the land surface of the Earth settled down, the survivors had room in which to spread themselves. At once there was a remarkable evolutionary efflorescence in which birds and mammals seemed to try to fill the environmental niches left vacant by the dinosaurs. They grew to considerable size.

One variety of rhinoceros, "Baluchitherium" ("beast from Baluchistan"), grew to a mass of about 30 tons. The largest bird that ever lived was the "Aepyornis" ("tall bird") of Madagascar that may have reached a weight of half a ton.

These experiments in size proved failures, however. Large birds cannot fly and could not compete with larger and fiercer mammals, so

that on the whole, the large birds were not evolutionarily successful. The smaller, flying birds proved the wave of the future.

As for the large mammals, they proved unsuccessful, too.

As it happened, the mammals had an important advantage over the reptiles over and above the existence of warm blood and a placenta. They had more specialized and better developed brains.

As long as dinosaurs existed and the mammals were tiny, their brains were not of much use to them, but with the dinosaurs gone, and the mammals increasing in size, those that made use of their growing brains rather than their growing bones and muscles gradually gained dominance.

And so here we are — thanks always to the amniote egg.

Responses to "Just Say 'No'?"

WE RECEIVED many responses to Dr. Asimov's controversial May essay, which discussed the flight from our cities and drug and alcohol abuse. The replies were very equally divided between the yeas and nays, but we have chosen to print mainly the latter, on grounds of equal time and because the letters of disagreement tended to be of more interest.

In "Just Say No!?", Dr. Asimov assumes that the reason people choose not to follow his preference and live in New York City is because they fear crime there, that the use of illegal drugs causes crime, that poverty causes people to use drugs, and that, as the logical conclusion to this syllogism, the rich should grow poorer and the poor should grow richer. This is the old liberal line, and Dr. Asimov says that he is a liberal. That he has the right to hold this opinion, I strongly affirm; he could reciprocate by affirming my right to believe in telepathy and psychokinesis, but I won't hold my breath until he does.

As for living in New York, where honest men cannot even defend themselves on the subway without being prosecuted and persecuted by the "liberal" legal establishment, of course, he can live there if he can afford the very high cost of decent housing, and he obviously can. Even if I wished, I cannot *afford* to live in New York, *even if I wanted to.* I happen to like London, Tucson, and Lima; I happen to dislike Calcutta, Tokyo, Los Angeles and New York. By preference, I like the tranquil

life in an Ozark town. Rolla is my home town, just as New York is Dr. Asimov's home town, so I can at least partly comprehend the emotional reasons for his preference. Too, his defense of life in New York is essentially Elijah Bailey's predisposition, expressed better in *The Naked Sun*, while I would probably prefer to avoid the Caves of Steel and enjoy clean air on one of the Outer Planets, if I live long enough.

I completely agree with Dr. Asimov; I do not smoke or drink alcohol or use illegal drugs, not out of religious conviction, but because I hate to put that into my mouth which steals away my brain. Conversely, I have no objection to anyone else of legal age doing all these things, so long as I don't have to breathe his or her smoke, and so long as he or she does not try to make me pay, directly or indirectly, for self-destructive choices.

However, I, as a lower-middle-class wage earner, have had enough of throwing money at social problems. If the people of New York City want to subsidize the joys of living where they choose, they can choose to use their earnings to do so, but not a penny of mine. If Dr. Asimov wishes to invite ten or twenty homeless people into his home, feed them, give them jobs, and wean any crackheads of their folly, then I applaud him as a kind and just human being. If he brings them to my home and expects me to do likewise, I fear I will disappoint him, for there is plenty of poverty in the Ozarks, and we need to import no more. And if he wishes to throw money at social problems to see if they will go away, he may throw his own — I have very little to spare, and a jolly hard time meeting my own necessary expenses.

— John Thomas Richards
Rolla, Missouri

I read Dr. Asimov's May column with admiration. First and foremost I admire his courage and his sense of writerly conscience in addressing a serious issue in a frank and forceful way, likely to offend many. And secondly, I'm in rough agreement with the line of his argument, which I read as suggesting that we Americans need to tackle our genuine and basic problems, not the fever-dreams of a pitchman who ran the country on subterfuge and astrology.

Whether a decent future requires us all to become teetotalling health-freaks is perhaps another matter. Should I really kick my cigarette addiction for the good of the nation? After all, I also drive a car, which, like my cigarettes, vilely soils the lungs of innocent passers-by. But unlike cigarettes (or crack, for that matter), our cars seem to be ravaging the landscape, the ozone layer and our planet's climate. This seems to me a far more serious problem than any number of trumped-up Reaganite dope-wars.

Perhaps we should prohibit private cars and strongly restrict the burning of fossil fuels. But that would require a real sacrifice by literate well-to-do white people, when it's much easier to blame all our troubles on black dope-addicts. Poor ghetto-dwellers strung out on crack don't have any voice in the corridors of power, and they make convenient scapegoats.

Actually, if there's any blame to be distributed for the patent decline of our country, it clearly belongs to the rich and powerful. The rich and powerful control the American government and economy, and they make what passes for important social decisions around here. If they're loopy on dope or booze, as they often are, then they generally

have the ability to discreetly hush it up; or, at worst, recover in the relative luxury of a Betty Ford clinic.

Nobody's gonna kick in their doors and blood-test them by force; that privilege, I suspect, will be reserved for hippies, dissidents, illegal aliens and the lumpen.

Junkies are not nice people. But I'm far less afraid of junkies than I am of the prospect of an authoritarian police force and a US Army ready to invade small countries at the drop of a sombrero. There are people around who really want this to happen. If it doesn't, then we will owe thanks to American citizens of the caliber of Dr. Asimov.

— Bruce Sterling
Austin, Texas

Dr. Asimov admits that he does not know if the people of East Germany are moving in the direction of greater freedom, or of a higher standard of living. This is precisely the failure of Liberals: not understanding that the two are related and inseparable.

Liberal law has helped make our cities dangerous and unlivable. Liberal rent-controls have frozen properties into perpetual decline. Liberal welfare has created a permanent underclass. Liberal fiscal irresponsibility, all by its lonesome, has created the near bankruptcy of not just cities, but also states like Massachusetts and New York (or are Dukakis and Cuomo suddenly Conservatives)? The result: our cities, and long before Reagan was here to blame for it.

More of the same Liberal snake oil that people have gotten so tired of! Share the wealth (just what are Eastern Europe and suburbanites fleeing from if not from egalitarian Liberal-Socialist-Marxist redistribution of what turns out to be poverty after it's been tinkered with by your friendly political boss)? Make people do what Papa Liberal knows is good for them (as announced by the brightest and most arrogant Liberals): stop smoking, stop drinking, tax and spend and elect, let paternal government share your wealth for you since WE KNOW BEST. It's all in Dr. Asimov's essay. Phooie!

It puts me in mind of the old Conservative saying: It's not that Liberals are ignorant; it's just that they know so much that simply isn't so. Liberalism, along with its siblings, Socialism and Marxism, are ideas whose times have come and, mirabile dictu, gone. A revised quotation from the Liberal era: we have seen the (leftist) future and it sucks! Ask anyone in Europe, or fleeing from our major cities.

— Peter H. Vennema
Lafayette Hill, PA

For me to make any kind of reply to your essay in the May issue just isn't possible. All I can say is that if certain candidates had some of the fire, commitment and calm reasoned smarts that you show in that essay, the Democratic party would not be in the trouble that it's in (at the national level).

You are sure to get lots of negative mail from the troglodytes. Remember how the composer Max Reger responded to his critics: "I am sitting in the smallest room in the house. I have your critique before me. Shortly it will be behind me."

— Al Zelaya
Morristown, N.J.

My husband and I are middle class small business owners. I am a smoker and enjoy a social drink now and then.

We live in the country in a modest home and our children go to a fine, small town school. I believe that we are living the "American Dream." We have worked very hard to accomplish what we have and will work just as hard to expand our business so that we can enjoy our lives even more. As we do this, we put more and more breadwinners on the payroll. Now, we could be taxed even more than we already are, in which case the government could give the poor, non-working people more money to live more comfortably. Of course, in order to pay those taxes we would not be able to expand our business, putting potentially productive people out of work. But why should they care? If the ones who do work have to share and share alike, why work? In fact, it sounds a lot like those countries whose people are complaining of shortages and non-productivity, doesn't it? Why do you think that this country is the richest in the world? Why do you think your parents moved to this country? It is because anyone who wants an education can get one. Anyone who wants to work can find a job. Some people will scoff at those statements and say, "What does that white, middle class woman know about the poor finding jobs and getting a decent education?". Well, I lived in the city and there were hundreds of businesses looking for clean, hard-working people to employ. A limited education is free, and scholarships and student loans are available to anyone who wants to pursue them.

I believe that we should take care of the sick and elderly. We could do that much more effectively if we could get the lazy, able-bodied off our welfare rolls.

Drinking and smoking are vices which we could all do without. I believe that there should be stiff penalties for those who endanger others' lives while using alcohol. I believe that smokers should be segregated from non-smokers. I also believe that if this is to remain a free country, those of us who choose to indulge in these vices should have the right to do so.

— Debbie Richardson
Montague, California

Isaac Asimov is a compassionate and concerned man, and the social ills he describes are real enough. Unfortunately, his prescription seems to be more of the same medicine that has not only failed to cure, but has largely brought the trouble on.

Statism may conceivably work in small, homogeneous countries — though Sweden is now on the verge of bankruptcy and Britain was headed for the Third World before the Thatcher cabinet put on the brakes. It is totally inappropriate to the huge, heterogeneous USA. The New Deal did not ease the Depression; after a brief upturn, our economy went downward again until World War II. Having spent billions of dollars and caused an amount of disruption and heartbreak that social scientists were appalled to measure, Urban Renewal triumphantly presented us with several thousand fewer housing units than we had before. The welfare system has demonstrably undermined or destroyed family life, especially among the black poor, and created a permanent underclass. The more public money we pour into education, the worse its performance. Small businesses collapse under a load of regulations, paperwork, and taxes with which big corporations readily cope while milking us for subsidies

and cost-overrunning contracts. The campaign against drugs, costly, futile, and erosive of everybody's liberties, likewise comes to you courtesy of your government.

Changes made under the Reagan administration were actually slight, but to the extent that they favored freedom, beneficial. Though the rich did get richer, so did the majority of the poor. The defense buildup broke Soviet will. The trade imbalance is a bugaboo.

What we need is not less individualism but more. Why not make direct cash payments to the needy, to spend as they see fit. Why not issue vouchers for schools? Why not let adults (I agree that children need protection) ingest whatever they wish, but leave the results to private philanthropy and Darwinian selection to cope with? Why not put people back in charge of their own enterprises and lives? Unlike most intellectuals, I have some confidence in the intelligence and decency of the average person.

It is ironic that, at a time when the shackles are falling off abroad, our politicians want to fasten new ones on us.

— Poul Anderson
Orinda, California

I was very disturbed after reading "Just Say No." You seem to be implicitly advocating a Communistic society through a massive redistribution of the wealth produced by a few and giving it to the many. (The aberrant system practiced by the Russians and the Chinese are tyrannical dictatorships and can only be called communistic by someone using George Orwell's doublespeak.) The early English settlers tried to establish a communistic society in Virginia based on the principle "From each according to his abilities, to each according to his needs." The colony almost perished until Captain John Smith established a new system, "He who does not work, does not eat."

A few years ago the Club of Rome predicted that our current society would collapse within the next century and that it was already too late to prevent the collapse. They listed several possible causes including Population, Pollution, Energy, Resources, and Food. They were unable on the basis of their computer simulations to decide which of these factors would be the final straw. My personal choice is Population, since uncontrolled population growth exacerbates all of the other difficulties.

Numerous studies have shown that when any animal population exceeds the carrying capacity of an ecosystem, the animals begin to act in erratic and irrational ways. In the case of Homo Sapiens, this trend is beginning to show up in the crowded conditions in our major cities. People need a minimum amount of personal space. This is one of the major reasons why public transportation has been unable to replace private cars for the movement of people around relatively short distances in a local area. The only way that the irrational behavior of the animals can be corrected, is by reducing the number of animals per unit area. Unfortunately this solution is unacceptable. It has been estimated that if the present rate of population increase continues the population of the earth will reach 10 billion by the year 2050. If the population does reach this level our current problems will increase exponentially. It may already be too late to prevent the inevitable collapse of our current civiliza-

tion because most of the population increase is occurring among those least able to take care of himself or herself let alone contribute to the progress and welfare of the society as a whole.

We are currently experiencing a worldwide example of the "Tragedy of the Commons." When an area is owned in common and used by all, all will use it as if it were their own, but no one will assume the responsibility for the preservation and protection of the commons. At first the commons were local, then statewide, then national, and now worldwide. As a result we have polluted our common stock of water, land, and air so that life is no longer tolerable in the major cities of the earth.

As a result the only rational behavior available to those who have the ability and the resources is to flee the central city and go to the suburbs where an acceptable quality of life is still possible. As those with the ability and resources flee to the suburbs, life in the central cities for those who remain becomes even more intolerable. Because of their increasing misery, it may well be that the only behavior available to them is to try to deaden their sense of misery and hopelessness by resorting to alcohol, drugs, and sex. They cannot just say no.

For those of us who can flee to the suburbs, we can only say with Rhett Butler: "I want peace. I want to see if there's something left in life of charm and grace."

— Robert W. Sandberg
Appleton, Wisconsin

I would like to thank Dr. Asimov for his essay "Just Say 'No'" in the May issue of F&SF. It is so extremely rare to have someone outline the drug issue (or any other issue for that matter) with such sanity and clarity, and in a plain-speaking manner with a minimum of rhetoric, that you will undoubtedly be flooded with angry letters provoked by the Good Doctor's refusal to toe the politically acceptable line of hysteria. Both you and he should consider such a response as a tribute: maybe for every ten letters you receive, one person will have been started on the road to clear thinking.

Congratulations.

— Edward R. Fitzgerald
New York, N.Y.

SCIENCE

ISAAC ASIMOV

TARGET: EARTH

I WAS IN the hospital for a period of time recently. (I couldn't help it. As the body grows older, it gets creakier and has to go to the garage now and then for an overhaul.)

While I was there, the head nurse came in and asked me if I would be kind enough to see the State Inspectors, who were due to come by, and if I would answer any questions they might ask me as to the quality of the care I was getting. Well, I was getting very good care, as it happened, and I was perfectly willing to say so.

The Inspector came by as I was waiting at the door of my room (I was perfectly ambulatory), and I promptly told her what she wanted to know — that the nurses were all young and pretty, that they came promptly when signalled, that they were cheerful and helpful, and that the hospital food was helping to keep my weight down.

Whereupon the patient in the next room, hearing all this (I was speaking in a good, firm voice) stepped out and growled at the Inspector, "Listen, don't believe a word he says. He makes things up."

I started indignantly. There are two insults I won't take from anyone — that I am dishonest and that I am a liar. I was about to assault him hip and thigh, when I realized, just in time, that all he meant was that I was a professional writer of fiction. In short, he knew who I was.

So I simply said, in the mildest possible way, "That's true, but I also write non-fiction, and I'm talking in the non-fiction mode right now."

Yet non-fiction can be more disturbing and sometimes harder to believe than fiction.

In ancient times, when people believed that Earth (and usually just the small patch of Earth with which they were familiar) was virtually all there was to the Universe,

and that the heavens were just a spangled canopy designed to light the Earth and to look pretty, there was no feeling that the Earth was in any danger from the sky.

To be sure, you could never tell what an irritable, short-tempered god might do. Thus, we read in the Bible that when God destroyed Sodom and Gomorrah, he "rained upon Sodom and upon Gomorrah brimstone and fire from the Lord out of heaven." (Genesis 19:24)

We don't know what that means, literally, and we don't even know if Sodom and Gomorrah ever existed, for we have found no ruins that can be identified with them. Still, is it possible that an object from heaven (a sizable meteorite) struck and destroyed them? (There is no evidence of that, either.)

Then, too, I have a pet theory of my own concerning the great flood that devastated the land of Sumeria about 2800 B.C. There *was* a large flood at that time, a not-uncommon thing in any river valley, but the Biblical account of its having covered the entire Earth cannot be taken literally. We must remember that, to the average Sumerian, Sumeria *was* the entire Earth.

The Bible says, "In the six hundredth year of Noah's life . . . were all the fountains of the great deep broken up, and the windows of heaven were opened." (Genesis 7:11).

By the opening of the windows of heaven, the Bible obviously means that it rained heavily. What does it mean, though, when it says that "all the fountains of the great deep" were "broken up." The "great deep" is, of course, the ocean, but how does this come into it? Consider, though, that Noah's Ark was supposed to come to rest in the mountains of Ararat (what is now Armenia), which is far to the northwest of Sumeria. The natural lie of the land slopes downward from northwest to southeast. The great rivers, the Euphrates and the Tigris, flow southeast in precisely the opposite direction from that in which the Ark drifted. How could it drift upstream?

Suppose, though, that a meteorite of considerable size struck the waters of the Persian Gulf and set up a huge tidal wave. That would sweep up the Sumerian valley in the direction opposite to the flow of the rivers.

It would be nice if someone could find a crater in the floor of the Persian Gulf that is not quite five thousand years old, but I don't think anyone has ever looked.

Although the ancients did not record meteorites as falling upon Sodom, or upon the Persian Gulf, they knew that meteorites fell. Occasionally, one would be seen to fall, and it would seem obvious that it had been sent by the gods. It

might be a warning against sin, or a sign of approval.

In any case, such meteorites were often considered holy. The Black Stone in the Kaaba, Islam's holiest shrine, is probably a meteorite (no one is allowed to test it, of course). A stone from heaven was worshipped in connection with the mother-goddess, Artemis, at the ancient city of Ephesus. The occasional bits of nickel-iron found in the soil that were meteoric in origin were sparingly used for tools, since the metal was stronger and tougher than the usual bronze.

The trouble was that these stories of occasional falls from heaven were so interlarded with mythological interpretations that in modern times, when science began to overtake mythology, scientists were in no mood to take such tales seriously.

A German physicist, Ernst Florens Friedrich Chladni (1756-1827), was an exception, however. There were peasants who claimed that they had actually seen stones falling from heaven, and although they were peasants and, therefore, by definition, moronic and superstitious, Chladni decided to keep an open mind and investigate. He travelled to the sites of reported falls and actually picked up pieces of meteorites and began a collection. In 1794, he published a book suggesting that meteorites were the remnants of a primordial planet that had, for some reason, exploded.

In 1803, a French physicist, Jean Baptiste Biot (1774-1862), also investigated reports of falls from heaven and travelled to the sites. He produced such a comprehensive, thoroughgoing, and convincing analysis, that an increasing number of scientists came to accept the possibility of meteorites from the sky. Perhaps this was made easier by the fact that, beginning in 1801, a few small planetary bodies ("asteroids") were found in the regions between the orbits of Mars and Jupiter, and astronomers first came to realize that there might indeed be cosmic debris in the sky.

We now know that the neighborhood of the Earth is dusty and gravelly and that, as our planet moves through space, it collides with something like 100 billion bits of matter every day. The vast majority of these bits are tiny dust particles that do not affect us significantly (except perhaps to serve as nuclei for raindrops, making them essential to our weather pattern). About 25 million of them a day are large enough to heat up and sparkle as meteors or "shooting stars" here and there in Earth's sky. These quickly evaporate and never reach the surface except as dust and gas.

A few, a very few of the meteors

are large enough to survive the passage through the atmosphere and to reach the Earth in the form of visible chunks, whereupon they are styled "meteorites." There are about 25 such falls each year, though only a fraction of these are actually located. About a thousand meteorites are known, although large numbers are now being found in Antarctica where, against the snow, *any* visible piece of non-snow that is not human-made must be a meteorite.

The largest known meteorite that has been discovered in one piece is in Namibia in southwest Africa and has an estimated weight of about 60 tons. No one has thought of trying to move it. Another meteorite, discovered by the American Arctic-explorer, Robert Edwin Peary (1856-1920), weighs 31 tons. It was moved and is on display at the American Museum of Natural History, where I have seen and touched it many times. It is the largest meteorite "in captivity."

The knowledge of the existence of meteorites, even the very occasional one that has a mass in the ton-range has never frightened humanity. One might zero in and hit me in the head and kill me instantly (they travel at 30 kilometers a second, or so), but the chance of that is infinitesimal. The dangerous meteorites are very few and Earth, as a target, is huge.

There is no known case of any human being having been killed by a meteorite. One that fell in Egypt in 1911 is supposed to have killed a dog. In 1938, a meteorite struck a garage in Illinois and buried itself in a car inside the garage, but there was no one in the car. In 1954, a woman in Alabama is reported to have been stuck and bruised by the ricocheting fragment of a meteorite.

Is there any evidence for the existence of meteorite falls other than the experience of having some strike Earth? Indeed, yes. Long before science turned its attention to meteorites on Earth, something interesting turned up in connection with the Moon.

In 1609, the Italian scientist Galileo Galilei (1564-1642), having built a primitive telescope for himself, turned it on the Moon. He found at once that the Moon was more than a shining plate of heavenly material designed to illuminate the night sky. He found it to be a *world*, with mountains and with flat areas he called "seas." In addition, it seemed to be littered with craters.

Craters, such as those on the Moon, can be formed in one of two ways. Either a large body falling from the sky strikes the Moon's surface (a meteoric impact) and

gouges out a crater, or the crater is the fossil remnant of an extinct volcano.

People of Earth had no experience with meteoric impacts in Galileo's time, but had lots of experience with volcanic eruptions, so it was taken for granted that the Lunar craters were of volcanic origin. To be sure, they were much larger than Earthly volcanic craters, but the Lunar surface gravity is only one-sixth that of Earth's, so that a volcanic eruption of a given force would kick up far more material. Besides, if it were a matter of meteoric impacts, the meteorites would come from all directions, and those that came in diagonally would form elliptical craters, while volcanic eruptions would form only circular craters. Since the Lunar craters were all more or less circular, that seemed to settle the matter in favor of volcanoes.

The first person to question the volcanic origin seriously was an American geologist, Grove Karl Gilbert (1845-1918). He argued, in the 1890's, that the Lunar craters were altogether different in shape from Earthly volcanic craters, and that Earthly volcanic craters were almost always on mountain peaks, whereas the Lunar craters were at ground level. He could not, however, explain why the Lunar craters, if formed by meteoric impact, were circular rather than elliptical.

The answer to that came later and was worked out in 1929 by the American astronomer Forest Ray Moulton (1872-1952). He pointed out that meteorites hit the Moon at 30 kilometers per second or more and that the vast kinetic energy of a sizable body moving at such a speed, when suddenly converted into heat at the moment of impact, would result in a titanic explosion. It would be the explosion, not the impact, that would create the crater, and the explosion, like a volcanic eruption, would produce a circular crater.

In 1900, the American geologist Thomas Chrowder Chamberlain had advanced the "planetesimal theory" of the origin of the Solar system. He maintained that, originally, the dust and gas of the nebula out of which the Solar system was formed coagulated into relatively small bodies of planetesimals. These collided with each other, the larger ones growing at the expense of the smaller ones, until the full-sized planets were formed.

If this were true, then it became clear that when the planets were nearly formed, there would still be a number of planetesimals about and that they would form the last collisions with the growing planets, leaving craters as the marks of that final bombardment.

Chamberlain's theory is no longer accepted in the form in which he presented it, but in present-day theories of the formation of the Solar system, the planetesimals still exist, and the last ones have formed the craters we see on the Moon, for instance.

Since we have learned to send probes beyond the Earth-Moon system, we have found that the Moon is not exceptional in this respect. We have found craters on Mercury, Mars, Phobos, Deimos, Ganymede, Callisto, and on other worlds as well.

But if craters, formed by meteoric impacts, are so common in the Solar system, how did the Earth escape?

The answer is, it didn't. It received its full share.

Then why isn't the Earth covered with craters as the Moon and Mercury are? As it happens, the period of major impacts took up the first half billion years of the history of the Solar system. After that, most of the planetesimals were used up and things grew relatively quiet.

It means that the craters had four billion years in which to disappear. On the Moon, though, and on the other smaller airless worlds of the Solar system, there were no effects that sufficed to wipe out the craters. The craters on the Moon are as fresh now as they were four billion years ago.

Not so in the case of Earth. We have an atmosphere that erodes these features, as do the beating waves, the pouring rivers, and the falling rain. And after life developed on Earth, it, too, through its activities acted to erase all signs of the craters. The craters on Earth were there in the beginning, in other words, but they are not there any more.

This history of meteoric impacts in the Solar system is not frightening in itself. After all, meteoric impacts would seem a thing of the past, something that took place in the infancy of the Solar system and takes place no longer. To be sure, there are occasional pieces that weigh up to 30 or even 60 tons and fall on Earth. These undoubtedly caused devastation in the immediate area in which they fell, but it was far from enough to imperil the planet.

When we say "planetesimals" we're talking of objects with masses not in the tens of tons, but in the millions, billions, and trillions of tons. An impact with one of those would be serious indeed, even deadly, but surely those things are all gone.

Or are they? Beginning in 1801, the asteroids were discovered. They are planetesimals, if you like, and

the largest one, Ceres, is about 950 kilometers in diameter.

As time went on, more and more asteroids were discovered, all smaller than Ceres, most much smaller. Nowadays, some 3,000 asteroids are actually known, and some astronomers suspect there may be 100,000 altogether that have diameters of a kilometer or more. Even the smallest of these would produce devastating results if it struck the Earth.

But how can they do so? All the asteroids seem safely tucked away in the asteroid belt between the orbits of Mars and Jupiter.

But are they? The smaller an asteroid is, the more easily and drastically its orbit can be changed by the gravitational pull of Jupiter and other planets. The smallest asteroids will be constantly shifting their orbits slightly. Some will be pushed farther from Earth, but some will be pushed nearer.

The first asteroid to be discovered that had an orbit that carried it closer to the Sun than Mars ever went, was Eros, in 1898. If Earth and Eros were in the proper place in their respective orbits, they would be only 14 million miles apart. That is little more than half the minimum distance of Venus from Earth, and was the closest approach of any object then known, other than the Moon.

Of course, 14 million miles is a comfortable distance, and Eros gets that close only at long intervals. Still, Eros is 20 kilometers across, and there would be no objection (except by astronomers who want to observe it for one reason or another) if it stayed still farther away.

In the last fifty years, however, many more "Earth-approaching asteroids" or "Earth-grazers" have been discovered. At present about 50 of them have been definitely seen and their orbits plotted, and many can approach Earth much more closely than Eros ever does. They are mostly only 1 or 2 kilometers across, but that is enough to do terrifying damage. Some astronomers estimate there may be 1500 such Earth-grazers with diameters of more than half a kilometer.

And sooner or later, one of these Earth-grazers is bound to make contact with us, so you see the age of planetesimals is not *quite* over.

But in that case, we ought to have been struck in recent geologic history.

And yes, we have. Even in the 20th Century.

On June 30, 1908, something happened in central Siberia near the Tunguska River. Exactly what happened we don't know because no one was near enough to the site

to see exactly what had happened, and if he were, he'd probably not be alive to serve as witness. The closest person was 100 kilometers away, and even at that distance, the explosion was forcible enough to knock him off his chair. It flattened every tree for miles around and wiped out a herd of reindeer.

I have often reflected on the lucky chance that such an explosion, undoubtedly a meteoric impact, took place exactly where it did. If it had landed almost anywhere else, it would have killed anywhere from thousands to millions of people in a split-second. If it had landed in the ocean, it would have set up tidal waves that would have done the same. If it had landed on an ice-cap, it might have melted large sections, with drastic results. Central Siberia was one of the very few places in which it could have landed and done no harm to anything human or human-made. (This was 1908, remember. At the present time, I doubt there is any such desolation left on Earth. Wherever the next Tunguska-type explosion takes place it will undoubtedly do damage, from the severe to the horrendous.

I have heard it said that if the Earth had been six hours later in its turning, the Tunguska object would have hit St. Petersburg, the Russian capital. Nowadays, if a meteoric impact were to wipe out a major Soviet or American city, the victimized nation might suspect a first strike and instantly retaliate. (It doesn't bear thinking of.)

It was impossible to examine the Tunguska site for a long time. By the time Russia had organized an expedition, World War I had erupted. That, and the Russian Revolution plus the Russian Civil War, meant that it was not till 1927 that the first exploratory group approached.

It is now thought that what struck Siberia was a piece of a comet about 100 meters in diameter. It was probably mostly ice with an admixture of rock. The ice vaporized and exploded before it actually touched the surface of the Earth so that it left no crater and so that the devastation was spread over a wider area.

The Tunguska event is the worst known meteoric impact that took place while *Homo sapiens* roamed the Earth, but there were earlier impacts, too. We know of one that left behind the only object that clearly resembles a Lunar crater, although a very small one.

This crater is in Arizona. It is about 1.2 kilometers in diameter (or three-fourths of a mile) and 180 meters deep. Its rim is about 45 meters above the flatness of the desert that surrounds it.

The crater was first discovered in the 1880's, and it was taken to be an extinct volcano. G.K. Gilbert came to study it and announced that it had to be a volcano because it was circular. (It was this study that led him to consider the Lunar volcanoes, whereafter he came to the conclusion that they were caused by meteoric impacts despite their circularity.)

Nevertheless, the Arizona crater could not be dismissed so lightly. The region was rich in iron fragments, and that made it seem as though a meteorite had fallen. In 1905, an American mining engineer, Daniel Moreau Barringer (1860-1929), came to the site to try to locate the buried mass of the meteor which, as a solid lump of iron, would be enormously valuable. He failed. Perhaps it was buried too deep, or perhaps the iron had vaporized on contact, but his investigation did produce evidence that it was caused by an impact. After that, it was called "Barringer Crater."

Once Moulton had showed that impact craters would be circular regardless of the angle at which the meteor struck, all doubt was removed and it came to be called "Meteor Crater."

Meteor Crater seems to have been formed about 50,000 years ago, when Neanderthal man was the dominant form of existing hominid, and when no hominids had yet entered the American continents. The Meteor Crater was formed without the witness of human or near-human eyes.

Meteor Crater happens to be located in a desert that has been a desert for at least the 50,000 years since it was formed. That means there has been little water there, and little in the way of life, so that it has remained largely uneroded.

Elsewhere on Earth, there are less obvious circular features, usually best visible from the air, where one can see small circular, or partly circular, lakes, or where the vegetation takes on a kind of circular character. These are "fossil craters" that were punched into existence a few million years ago and have been largely eroded away.

A really *large* impact seems to have taken place 65 million years ago at the end of the Cretaceous period.* A true Earth-grazer seems to have struck the Earth then, and produced drastic results in the form of volcanic eruptions, fires, tidal waves, and stratospheric dust so that three-fourths of the species of living things on Earth were wiped out, and even the quarter that survived must have been seriously

**See YES! WITH A BANG (F & SF, June, 1981)*

depleted in numbers.

The large animals suffered particularly and, in the aftermath of this enormous strike, all the dinosaurs died off, for instance, after they had ruled the Earth for 150 million years. The crocodilians were the largest reptiles to survive. A horde of tiny mammals and birds survived, also.

Apparently, this was not an isolated event. Throughout evolutionary history there have been periods of "Great Dyings" in which vast numbers of living species suddenly disappeared. At least one such event was even worse than the Cretaceous. At the end of the Permian era, some 90 percent of all the species than extant were wiped out. It may be that all such periods were caused by meteoric impacts.

No meteoric impact has been severe enough to sterilize the Earth altogether and force life to start all over (if it could), but who knows what the next one will bring.

There are those who maintain that such meteoric impacts are an essential part of the evolutionary process. After a period of time, life on Earth gets too well-adapted to its environment and evolution starts heading for a dead end.

Comes a catastrophe and we start over. The species that are left alive, usually small ones, suddenly find that their predators are gone and that whole environment niches have been left empty. There is then a rapid evolutionary radiation, and all sorts of experimental forms are worked out that might never have been elaborated under the previous dispensation.

Thus, mammals and birds both grew large and, sometimes, fierce so that we had the baluchitherium, and sabre-tooth smilodon, the elephant-bird of Madagascar, and the giant moas of New Zealand. These were filling the dinosaurian niches and were not very successful.

The mammals had a chance, though, to experiment in a new direction, one that the dinosaurs in their time had never ventured into, and that was in the development of bigger and better brains. The primates, in particular, were successful at this, specializing in eyes, brains, and hands, and the result was, eventually, whether for better or for worse, the development of humanity and the first technological civilization the Earth had ever seen.

That's all very well, when we profit, but what if another impact comes in the future, wipes us out and gives some other small unregarded species the chance to radiate in all directions and to produce something that is not necessarily better or worse, but is distinctly and startlingly *different* from us.

The new dominant species would think this was great, but somehow I don't think we could work up any enthusiasm for such a change.

As early as 1959, then, I suggested that, once humanity gained the ability to do so, a Space Patrol ought to be established, similar to the Ice Patrol that reports on icebergs in the North Atlantic. If ever an Earth-grazer is noted whose orbit seems dangerous, it could be struck by one or more hydrogen bombs (or some more advanced device) that would convert it into rubble.

Of course, the rubble would continue to orbit the Sun, but if it ever approached the Earth thereafter, it would have spread out so that relatively few pieces would strike and those would do so at far-separated points. Then, too, most of them would be so small that they would do no damage of importance.

Since the meteoric impact that ended the Cretaceous was first advanced in 1981, some scientists have begun suggesting a Space Patrol in all seriousness, but no one has yet happened to notice that I was the first to do so.

SCIENCE

ISAAC ASIMOV

OUT OF THE TYPEWRITER, ENDLESSLY WRITING

LAST WEEK I received a letter which contained the following paragraph:

"Recently, I attended a training session on using OCLC (a widely used cataloguing and inter-library loan database) as part of my studies for the Master's in Library Science. Needing a search key that would retrieve a multitude of records, I used your name. Unfortunately, if a given search key would retrieve over 1,500 records, the searcher gets the 'request impossible' message and instructions to narrow the search and try again. Your name is just such a search key. I refined my search by going in under "asim, foun" (for works by Asimov with the word "foundation" in the title) and was able to retrieve a manageable search result."

There you have it. No one has ever accused me of being a great writer, but the word for me is "prolific." No one ever doubts that.

Actually, there are two writers of note who have written more than I have. The British mystery writer, John Creasey, has written something like 560 books, and the Belgian mystery writer, Georges Simenon has written over 500. Both are now dead.

I am, in all likelihood, the most prolific *American* writer who ever lived, with 451 books as of now (though a number of them are anthologies and other ancillary works), nearly 400 short stories and some thousands of non-fiction essays. (Many of the short pieces are included in my books, of course.)

If I live out a normal lifetime I might conceivably even beat out Creasey, though this is not the goal of my existence, so that if I fall short, I won't care.

What I am proud of is not the mere quantity of my writing, but its range. Creasey and Simenon wrote mostly, or entirely, mysteries, but I have also written science fiction (as you all know), and most

of my work is non-fiction. I have written on every branch of science at all levels from grade school to graduate school. I have also written books with titles such as *Lecherous Limericks, Asimov's Guide to the Bible, Asimov's Guide to Shakespeare, Isaac Asimov's Treasury of Humor, The Shaping of France, Asimov's Annotated Gilbert & Sullivan,* and so on.

In October 1989, I published two books. One was my most recent science-fiction novel, *Nemesis,* published by Doubleday, and the other a 400,000-word book entitled *Asimov's Chronology of Science and Discovery,* published by Harper's.

None of this was planned; it just happened. However, it has left me the world's best qualified expert on prolific writing, and I would like to devote this essay to that subject.

It means that I will be writing a personal essay, rather than on some learned subject, but the Noble Editor is very tolerant and allows me complete freedom of expression in this essay-series. Then, too, my last personal essay was THE WORD I INVENTED, in the October 1980 issue, exactly ten years ago, and one a decade doesn't seem excessive to me.

Will the readers be interested? I hope so. It is possible that a few among them have ambitions to be a writer, and they might wonder if, while they're at it, they might not be a prolific writer with a wide range. There are advantages to it, you see.

For one thing, you get more money for a large quantity of writing than for a small quantity of equal quality, and we all want to make a living of sorts in this uncertain world.

For another, if you build a reputation as a rapid and facile writer of good quality and wide range, you've got it made. Editors are forever being caught short and finding themselves in need of an article or story on some subject and, if the question, "But whom can we get to write it?" is raised, someone is bound to say (no matter what the subject matter), "How about Asimov?"

The result is that I have never written a query letter in my entire life. The query letters go the other way. Editors propose articles to me and I either write them or don't write them depending on my schedule and on the state of my expertise. (I don't *quite* know everything, and some subjects I can't write on.)

However, before you get all excited about the prospect, I must tell you that there are also serious disadvantages to being a prolific writer, as you will find out if you continue to read this essay.

Actually, I expect that very few

of my readers will have the dream of being prolific, but there may be many who are simply curious about the whole process — or possibly appalled by it. How does someone go about being prolific? What kind of personality is required? What kind of talents? What kind of life-style results?

I did not start off being prolific, as, for instance, Robert Silverberg did. I was going to school when I started, and I was also working in my father's candy store, and both items took precedence over my writing. The result is that in my first eleven years as a writer (during which time I obtained all my degrees, and managed to free myself of the candy store) I published only 60 science fiction stories, and not even a single book.

It was, in fact, not till my twelfth year as a published writer that my first book, *Pebble in the Sky*, appeared under the Doubleday imprint. It was published on January 19, 1950, when I had just passed my thirtieth birthday — an intolerably late start.

In retrospect, that first book was a milestone for Doubleday for, since then, they have published 112 of my books, making me the most published writer in their history. What's more, I have three more Doubleday books in press while others are under preparation. It is not surprising, then, that on January 16, 1990, they threw a big bash at Tavern on the Green to celebrate the fortieth anniversary of the publication of *Pebble*.

Unfortunately, I was in the hospital at the time, but I didn't see how I could disappoint hundreds of people. I sneaked out of the hospital, therefore, with my dear wife, Janet, pushing the wheel chair and my faithful internist, Dr. Paul Esserman, in attendance and came to the party, and even gave a funny talk (sitting down).*

Afterward, I sneaked back into the hospital in the fond hope that no one had noticed I was gone, but the *New York Times* printed a small story about it the next day, and everyone saw it. I was severely lectured by the nurses. Lester del Rey called me up to yell at me for risking my life. My pleas that I couldn't disappoint people fell on deaf ears.

Things continued at half-speed for another eight years after I published *Pebble* because I had a full-time professorial position at Boston University School of Medicine and *that* had to take precedence. How-

* *Incidentally, don't worry about me unduly. I got out of the hospital eventually, and while I'm not "as good as new" and never will be, I'm as good as a 70-year-old has the right to expect.*

ever, new people came in as the heads of the department of biochemistry and of the school, and they were utterly unsympathetic to my spending my spare time writing rather than doing research. So they kicked me out of my job in 1958, by which time I had only managed to publish 25 books.

(I fought like the devil, though. I wasn't interested in the salary or the professorial duties, but I insisted on keeping the professorial title and I won out. To this day, I am Professor of Biochemistry at Boston University School of Medicine. So far, they haven't inflicted on me the indignity of an "emeritus" status that would indicate I was overaged and retired, probably because they haven't thought of it. Good! I don't intend to remind them.)

On July 1, 1958, therefore, at the age of 38, I found myself out of a job and without an assured income. To be sure, that assured income had been microscopic — $6500 a year — and I made considerably more money out of my writing, but I felt nervous about the psychological aspects. Could I actually write full-time or would I quickly wear myself out and run my mind dry? Without the backing of an assured income would life become too insecure to be tolerated?

Feverishly, I threw myself into my writing chores in order to get what I could out of my mind while it lasted, and it turned out I had no reason to worry. In the 32 years since I turned to writing full-time, I have averaged 13 books a year (I'm my own book-of-the-month club).

So how is this done?

In the first place, you have to love to write.

By that, I don't mean that you love to think up plots, or to imagine you have written a best-selling book, or even occasionally to sit down and doodle a few paragraphs.

I also don't mean that you love to look at a finished book with your name on it and to wave it around for people to see.

I mean that you love what comes in between thinking about a book and displaying a finished book. You must love the actual operation of writing. You must love scratching your pen across a blank piece of paper, or pounding the typewriter keys, or watching words appear on the word-processor screen. It doesn't matter what technique you use, you have to love the process.

I imagine that the wood-working hobbyist loves to feel the wood shape under his fingers; that the devoted jogger loves the feeling of his legs consuming the miles; that the devoted swain loves the touch of the skin of his loved one.

Well, that's the way a writer has to love the process of writing if he wishes to be prolific.

Mind you, the ability to write does not necessarily equate into the love of the process. There are good writers — even, I imagine, great writers — who don't particularly like writing and who constantly find excuses not to write. There are facile writers who have no trouble writing once they start, but have trouble starting.

Thus, Sprague de Camp has stated that if you wish to write you must plan for four hours of uninterrupted solitude, because it takes a long time to get started, and if you are interrupted, you would have to start all over again from the beginning.

In fact, you can even be a *compulsive* writer and not love the process. We all have compulsions we don't particularly like. Some are external, and force us, for instance, to wake up in the morning when the alarm clock rings because otherwise we might lose our jobs. We respond by cursing the alarm clock and yelling at the children.

Some compulsions are internal, as in the case of people who have to wash their hands forty times a day, or (as in my case) are forced to go back to a just-locked door to make sure it is locked, or check to see if a typewriter has been turned off immediately after it has been turned off. When such inner compulsions get so bad as to interfere with life, you are likely to go to a psychiatrist to see if you can get rid of them.

A compulsion to write may be just as unpleasant to the writer as any other compulsion, and perhaps all the worse because he can't get rid of it without endangering his livelihood. No wonder so many writers become most ingenious in thinking up reasons not to write.

So general is the notion (and, probably, the reality) that writers hate to write, that there is a marked feeling among the public that writers must find some way of painfully psyching themselves into it.

I was once asked by someone what I did in order to start writing.

I said, blankly, "What do you mean?"

"Well, do you do setting-up exercises first, or sharpen all your pencils, or do a cross-word puzzle — you know, something to get yourself into the mood."

"Oh," I said, enlightened. "I see what you mean. The truth is that before I begin writing, it is always necessary for me to turn on my electric typewriter, and make sure my chair is arranged so I can reach the keys."

If I don't need any more psyching than that, then, in theory, I can type at any time, and, in practice, I

can. I don't need Sprague's four hours of uninterrupted time. If I have fifteen minutes, I can sit down and type for fifteen minutes. That's an absolute necessity if you wish to be a *prolific* writer.

On the whole, then, I think I can make the matter of loving to write even stronger. A prolific writer has to have a *passion* for the process. He has to want to write more than anything else in the world.

Sprague also once said: Suppose you sit down at the typewriter and look out the window and notice that it is a perfect day, with the sky blue, the grass green, the birds singing, a gentle breeze wafting — just the day to go out and lie in the sun, or play golf — and you say to yourself, "Well, I'll write tomorrow" and go out. In that case, he said, "You're not a writer and had better choose some other way of making a living."

Sprague may be a little too hard there. You may still be a writer, but certainly not a *prolific* writer.

I doubt that a pleasant outdoor scene could seduce me, but I keep the blinds down in my work-room at all times just in case. My favorite kind of day (provided I don't have an unbreakable appointment that is going to force me out into it) is a cold, dreary, gusty, sleety day. In that case, you see, no one I know (like Janet, as a wild guess) is going to come to me and say, "Let's take a walk in the park. It's such a beautiful day."

In fact, I can go farther. I won't say this has ever happened to me but I can easily imagine it. If you have a date with a girl and intend to spend a pleasant evening with her doing whatever it is that would make it pleasant, and if you are typing hotly and suddenly notice that you just have time to wash, get dressed, and leave for the date, you will mutter an expletive and wish you had made the date for the next day, or the next year. The fact is you would rather type, and that is what makes you a prolific writer.

If you try to be prolific without being passionate about the process of writing, you will break under the strain, for writing is notorious for breaking its practitioners. Writing without passion is like driving with the brakes on, like pulling an unwheeled cart over a rough road. You can't go on long without being forced to stop.

Why is this? As has often been pointed out, writing is a very lonely occupation. You can talk about what you write, and discuss it with friends, editors, or family, but when you sit down at the typewriter you are alone with it and no kibitzers can help you. You must extract every word from your own suffering mind.

It's no wonder writers so often turn misanthopic or are driven to drink (or worse) to dull the agony. I've heard it said that alcoholism is an occupational disease with writers.

Obviously a prolific writer can't afford any of these diversions, for with such indulgence he won't stay prolific. I, despite my day-and-night writing over a period of decades, don't drink at all, or smoke, or use drugs. What's more, I am known far and wide for my sunny disposition. Why is that?

Let me explain.

The writer's life is an insecure one. Each project is a new start and may be a failure. You may have sold a previous story or article, but that doesn't carry over. No editor is going to say, "This new story is no good, but the previous one was so good that the average still remains high, so let's publish this no-good new story."

Not at all. Whatever your batting average, the new story must stand on its own.

Knowing this, the writer is assailed by doubts whenever he writes. Is what he has written any good? Is that sentence phrased properly? Is he saying what he means to say, or is he being dull and obscure? The writer is always knitting his brow and puzzling over what he has written. He keeps making changes, which is very time-consuming and usually doesn't lessen his insecurity one bit. And this can easily drive him to drink.

Undoubtedly, repeated revising and sweating and altering and lip-chewing can polish up a story and convert a so-so something into a great work of literature. I don't argue that point.

What I *do* say, however, is that though you can sweat out each line and be a great writer, you can't sweat out each line and be a *prolific* writer.

A prolific writer, therefore, has to have self-assurance. He can't sit about doubting the quality of his writing. Rather, he has to *love* his own writing.

I do. I can pick up any one of my books, start reading it anywhere and immediately be lost in it and keep on reading until I am shaken out of the spell by some external event. My dear wife, Janet, finds this amusing, but I think it's natural. If I didn't enjoy my writing so much, how on Earth could I stand all the writing I do?

The result is that I rarely, if ever, worry about the sentences that reel out of my mind. If I have written them, I assume the chances are about 20 to 1 that they are perfectly all right.

I am not completely certain, of

course. Some writers, according to what I have heard, such as Robert Heinlein and the mystery writer Rex Stout, never change a word they have written and hand in first draft. I'm not quite *that* good. I do edit the first draft and make changes that usually amount to not more than 5 percent of the total verbiage, and *then* send it off.

One reason for my self-assurance, perhaps, is that I see a story or an article or a book as a *pattern* and not just a succession of words. I know exactly how to fit each item in the piece into the pattern, so that it is never necessary to work from an outline. It all comes out naturally. Even the most complicated plot, or the most complicated exposition, comes out properly with everything in the right order, and requires little in the way of rewriting.

I can't explain how I do this; it comes with the territory. A Grand Master at chess probably sees a chess game as a pattern, rather than as a succession of moves. A good baseball manager probably sees the game as a pattern rather than a succession of plays.

And I see patterns, too, in my specialty, but I don't know how I do it. I simply have the knack and had it even as a kid.

Of course, it also helps if you don't try to be too literary in your writing. If you try to turn out a prose poem, even a very good prose poet (like Ray Bradbury or Theodore Sturgeon) can miss sometimes. Even a slight miss in poetry can be terrible.

I have therefore deliberately cultivated a very plain style, even a colloquial one, and it is very difficult to do anything to spoil that. Of course, some critics, with crania that are more bone than mind, interpret this as my having "no style." If anyone, however, thinks that it is easy to write with absolute clarity and no frills, I recommend that he try it.

Another source of insecurity arises after a piece of writing (a novel, let us say) is completed and accepted and published. What will the critics say? How well will it sell? If it does not do well, you may not realize enough in the way of royalties to compensate you for the time you spent working on it. What's more, publishers may then be reluctant to take your next book, or may offer a smaller advance.

The mere fact of being prolific, however, removes much of that insecurity. By the time a book is published, the prolific writer has sold several others and is working on still others. He has no time to worry about the book that has just been published; he may not even remember it very well. He has more

immediate concerns in the typewriter.

Then, too, once enough books are published, a kind of "ever-normal granary" is established. Even if one book doesn't do well, all the books as a whole are bringing in money, and one fall-short isn't noticeable. Even the publisher can take that attitude.

Not one of my very numerous Doubleday books has caused them, as far as I know, an actual loss, but even if one did, it could be tolerated by them in the light of the general success of my books taken altogether.

With all the possible sources of insecurity, it is not surprising that writers often go into "writer's block." This is a painful disease in which they stare at a blank sheet of paper without being able to make marks on it. It is progressive, too, for the longer the inability to write continues, the more certain it is that it will continue to continue.

I imagine that if all a writer works on is a single task, it must wear him down and stop him eventually. Even I, when working too long and steadily on a particular project, am forced to stop when I cannot force another paragraph out of myself. In my case, though, this is not serious. I have a dozen other tasks to do and I just turn to some of them. By the time I am done, my mind has had a chance to relax and work out my problems. I can then return to the original project and resume the easy flow.

But what kind of family life does a prolific writer lead?

A prolific writer has to be self-absorbed. He *has* to be. He should be at his typewriter at least eight hours every day, including weekends and holidays. (In my younger days I used to manage, occasionally, to handle a fourteen-hour day, but age takes its toll. I can now only rarely manage even twelve hours.)

Even when a prolific writer is not at his typewriter, he's distracted. His mind (at any rate, *my* mind) keeps clicking away. I can hear scraps of dialog, bits of exposition, rolling past my mind whenever I am away from the typewriter. Even when I am not consciously aware of it, I know it's taking place.

That's why I don't need four hours of uninterrupted solitude to get writing. Everything is, in a sense, already written. I can just sit down and type it all out, at up to 100 words a minute, at my mind's dictation.

Further, I can be interrupted and it doesn't affect me. After the interruption, I simply return to the business at hand and continue typing under mental dictation.

Of course, all this means that

you are not really a family man. Janet is tolerance personified and is very fond of me and of all my quirks and peculiarities, but even she is sometimes goaded into remarking that we don't talk to each other sufficiently.

My beautiful, blonde-haired, blue-eyed daughter, Robyn, is very close to me. We love each other dearly, and recently I asked her, "Robyn, what kind of father have I been?"

I wanted her to tell me I was a loving father, a generous father, a warm and protective father (all of which I like to think I was, and am), but she thought about it and finally said, "Well, you were a *busy* father."

I imagine it does weary a family to have a husband and father who never wants to travel, who never wants to go on an outing or even to the theater or movies, who never wants to do anything but sit in his room and write. I dare say that part of the failure of my first marriage was the result of this.

But there's nothing I can do about it.

All this may totally disillusion you with being a prolific writer. You may well decide that the price you must pay is far too high, that it means allowing life, with all its glories, to pass you by.

My first wife once said, bitterly, as I was closing in on my hundredth book. "What good is all this, Isaac? When you are dying you will realize all you missed in life, all the good things you could have afforded with the money you make and that you ignored in your mad pursuit of more and more books. What will a hundred books do for you?"

And I said, "Dear, when I am dying, lean close over me to get my dying words. They are going to be, 'Heck, only a hundred!'"

Well, my 451st book will reach me today, and if I should now find myself dying, I would murmur, "Heck, only four hundred fifty-one!"*

That leaves only one thing to discuss.

Suppose you have a passion to write and you turn out story after story, article after article, book after book. How can you manage to work *so* quickly and revise *so* little and still turn out books that a publisher would want to publish and a reader would want to read?

Ah, there you have me!

There's something called inborn talent, and what that might be, and how that might work, I haven't the faintest idea.

I apparently have it, and because of that I am, and have always been, a successfully prolific writer, and because of *that*, the happiest man in the world.

* *Actually, they would be my next-to-last words. I would want my very last words to be, "I love you, Janet."*

SCIENCE

ISAAC ASIMOV

THE INVENTION OF THE DEVIL

I HATE BEING photographed. No, let me make that more specific — I hate posing for photographs. I don't mind being snapped while I'm doing something else. I simply don't notice it. But to stand around with a glassy smile, holding my hands this way and that for a hundred different poses, strikes me as unnatural and as an abominable waste of time.

I was once participating in the publicity for a video game version of my robot novels in a gloomy warehouse with lots of raucous music, and with photographs being taken endlessly. I had to pose with different people in different ways and different smiles, feeling my temper frazzle more and more.

I was worn nearly to death by the time the photographers stopped, but then a tall, dignified-looking man arrived, and all the photographers burst into a renewed frenzy of activity. I was dragged over and made to stand beside the man, and the picture taking resumed.

He seemed indifferent to the matter, but I wasn't. In an extreme of controlled fury, I turned to my companion, and said, "I think that photography is the invention of the devil, don't you?"

And he smiled and said, "I hope not. I'm the president of Eastman Kodak."

That was a conversation-stopper indeed, and just to make sure you understand why, I think I will write an essay that will sneak up on Eastman, and on Kodak as well.

From the very earliest period of the existence of *Homo sapiens* our species has had the urge to indulge in representational art. That is, people have labored to draw lines and apply colors, or to carve ivory or wood, into shapes that resemble real, familiar things. The idea is to have someone who has not made the artwork, or even seen it being made, look at it and say the equi-

valent of, "Hey, that looks like a man hunting bison with a bow and arrow."

Why this impulse? Perhaps it was an attempt to adjust fortune. By showing an animal being shot by an arrow, you were explaining to the gods that what you wanted was to make a kill the next day, so that you might eat rather than starve. Or perhaps it was just the esthetic sense, the desire to do something that looks good and that other people will see and admire and praise you for.

The knowledge of such primitive art first came about 1860, when a French paleontologist, Edouard Armand Lartet (1801-1871), unearthed a mammoth tooth with an excellent drawing of a mammoth scratched into it. The drawing was accurate enough to make it certain that the artist had seen a mammoth in life, so that it was old enough to date from the time before mammoths had become extinct. What's more, it had to be made by a human being, for we know of no other species than our own that ever engaged, or could engage, in representational art.

(To be sure, chimpanzees have produced finger paintings which art experts have thought to have merit, but such paintings are "abstract art." One can conclude that a chimpanzee brain is sufficient for abstract art, but that a human brain is required for representational art. I'm not trying to make an artistic judgement here, I'm just stating what seem to be the facts.)

An even more startling discovery was made in 1879, when a Spanish archeologist, Marcellino de Sautuola (d.1888), was excavating Altamira Cave in northern Spain. His twelve-year-old daughter, who was with him, spied paintings on the ceiling and called out "Bulls! Bulls!" There were paintings of bison, deer, and other animals in red and black, and they were perhaps drawn as long ago as 20,000 B.C. So well were they done, that many people refused to believe they were truly ancient, but thought them to be a modern hoax. It was only with the finding of other caves and paintings, that the art was finally accepted as ancient.

Ancient figurines have also been discovered, often of the female form in distorted ways, showing enormous breasts and buttocks. These may have been fertility symbols, too, though I had a professor once who thought that the sculptors simply emphasized the parts that interested them most.

I can't very well proceed now to give a detailed history of the further development of art. I don't know enough about it, for one thing. However, sculpture reached a degree

of perfection with the Greeks of the Classic age, as we all know.

Painting was a little trickier. We don't have many examples of ancient painting, but we know that there was never any really successful representation of a three-dimensional illusion on the two-dimensional surface of a painting till Renaissance times. (This is not to say that a three-dimensional illusion is essential to a great painting; only that it makes the "representation" of the scene seem more real, for what that's worth.)

What was required for the presence of a three-dimensional illusion was an understanding of the laws of perspective, and this meant the application of geometry to art. The first to do this in a methodical way was the Italian artist Leone Battista Alberti (1404-1472) who, in 1434, published a book on the laws of perspective. That gave us the masterpieces of such other Renaissance artists as Raphael (1483-1520) and Leonardo da Vinci (1452-1519), and of later artists such as the Frenchman Jacques-Louis David (1748-1825).

I always love to look at David's paintings because they manage to look so accurately drawn as to resemble a photograph, and to my untutored eye, photographic reality is the essence of pleasant art.

However, it was precisely that look that put an end to the popularity of representational art. Once photography came into being, what was the point in preparing art that looked like photographs? For that reason, artists turned to surrealism, impressionism, abstractionism, and other forms of art that moved beyond bland reality into the realm of impressions, emotions, moods, or the mere esthetic appreciation of lines and colors cleverly arranged.

But how did it come about, then, that photography was invented?

Photography can be traced back to its most primitive beginnings, if we consider eclipses of the sun. Any astronomer who wanted to study an eclipse had difficulty doing so without blinding himself. People must have noticed, however, that Sunlight passing through small apertures, such as the spaces between tree leaves, produced small circles of light on the ground that looked like images of the Sun.

Suppose, then, that you made a small hole in the wall of a dark room. Wouldn't an image of the Sun be cast on the opposite wall, or on the floor? To be sure, light enters the hole in slightly different directions so that the image is fuzzy. The smaller the hole, however, the less room for different directions, and the sharper the image.

The Arabian physicist Alhazen

(965-1039) was the first to describe this phenomenon and recommended it for observing solar eclipses, since the image of the Sun faithfully reflected the encroaching Moon and was sufficiently dim to be observed without optical damage. The Italians called this trick of using a dark room with a pinhole for the entry of Sunlight, a "camera obscura," which is Italian for "dark room." We still keep the word "camera" for any closed box, large or small, within which an image is formed.

For five hundred years, pinhole cameras were used only to study the Sun. Nothing else was bright enough to send enough light through a pinhole to make useful observations possible.

In 1550, however, it occurred to an Italian mathematician, Girolamo Cardano (1501-1576), to use a wider hole with a biconvex lens fitted into it. The wider hole admitted much more light, and the lens brought it to a focus. For the first time, easy-to-view images could be produced of, let us say, street scenes. The trouble was that the image was produced upside down. (This wouldn't matter in the case of the Sun.) Worse yet, whereas a pinhole camera could form an image that was well-focussed at any distance, a lens camera would focus the image only at a certain point so that the surface on which the image was formed had to be thus far from the lens and no farther or closer.

In 1568, the Italian scientist Daniele Barbaro (1528-1569) introduced a diaphragm that could cut down or increase the quantity of light entering a lens, and, in 1573, another Italian scientist, Ignatio Danti (1536-1586), introduced a concave mirror in such a way that the image was re-inverted and shown right-size up.

By 1558, the Italian physicist Giambattista della Porta (1535-1615) was suggesting that the images produced by pinhole cameras could be used by artists who could trace the outlines of the image and, in this way, learn the subtle uses of perspective.

Of course, using a large room for the purpose had its disadvantages, compared to some portable object within which the image could be formed. It was not till 1657, however, that a really successful portable camera was devised by the German scientist Caspar Schott (1608-1657) It consisted of a small box inside a larger one. The smaller could be moved back and forth to improve the focus. Other improvements were made, and, by 1685, the camera in its basics was just about the one we use today.

All that was now needed was a *permanent* image, but how could

that be produced? Surely, it must have seemed an impossible achievement in 1685, and people might well have supposed that the camera would never be used for anything but to amuse people with little duplications of what was going on outside, and to help artists practice their perspective.

People had noticed, though, that silver compounds, which were white, tended to darken in Sunlight. The cause was not known. It might be the Sun's heat or something in the air.

In 1727, however, a German scientist, Johann Heinrich Schulze (1687-1744), was the first to show that it was light that was responsible.

He made use of this phenomenon to carry out the following demonstration. He began with a beaker containing a solution of silver nitrate and added enough chalk to make it a semi-solid slurry. He then covered it with paper in which he had cut out holes in the shape of letters. He placed the beaker in the Sunlight. Where the light passed through the holes, it darkened the material beneath, while the parts covered by the paper remained white. In this way, he "wrote with light" and, in Greek, that is "photography." It was just a cute trick, however, and was put to no practical use.

We know what happens. Silver is a rather inert metal and does not very readily form compounds. When it does form a compound, that compound is comparatively easy to break up. Sunlight possesses enough energy for the purpose and liberates a silver atom from molecules of the compound. The silver atoms coagulate into tiny fragments that are black, and so the white compound darkens.

After that, for over a hundred fifty years, chemists studied the darkening effect of light on silver compounds and occasionally tried to form images as Schulze had done. The trouble was that these images could not be made permanent. A portion of the silver compounds might be darkened while others remained white, so that nice images could be formed, but as the silver compounds remained in the light, even in diffuse daylight, it all gradually darkened and the image was lost.

That brings us to a French inventor, Joseph Nicephore Niepce (1765-1833). He was interested in lithography, a form of art that involved the placing of greased designs on stone. He had no artistic talent of his own, and his son made the designs. When the son was called up for military service (Napoleon was fighting his last battles), Niepce tried

to work out a way of producing designs automatically.

Images on silver compounds didn't work for him any more than for anyone else, so he tried to use a thick asphalt-like hydrocarbon. This didn't darken in Sunlight but it did harden. He dissolved the asphalt in lighter hydrocarbons and smeared a thin layer on a metal surface. He would then allow the light to pass into a camera onto the metal. Wherever light fell, the asphalt would grow hard; elsewhere it would stay soft. After that process was done, he could use solvent to remove the soft asphalt while the hardened asphalt remained behind. In this way, he obtained a more or less permanent duplicate of the original scene. It might be called an extremely primitive photograph.

He produced the first such photograph in 1827 and tried to interest investors in the process, but the exposure time was eight hours, and that made it nothing more than a tedious curiosity. Niepce was further hampered by a wastrel brother, and he was forced into bankruptcy.

Meanwhile, another Frenchman was working on the problem of preparing a permanent image. He was Louis Jacques Mande Daguerre (1789-1851). He was connected with the theater, for he was an artist who specialized in painting scenic backdrops. To make the backdrops more entertaining, he invented the diorama, consisting of optical effects in which real objects were made to blend in with a painted background and in which different scenes might be displayed successively — to give an effect, for instance, of changing seasons.

Then he began working on the problem of permanent images. In 1829, he went into partnership with the bankrupt Niepce and learned all that the latter had done. From there, Daguerre carried on.

He returned to silver compounds, depositing them on a metal plate. When light, reflected from an object, fell on the plate, parts darkened as always, but now Daguerre added something new, thanks to the work of the British astronomer John Frederick William Herschel (1792-1871).

Herschel had pointed out that a solution of the compound sodium thiosulfate (usually called "hypo" by photographers) could dissolve undarkened silver compounds. It did not affect the tiny black grains of silver metal.

After Daguerre got his image of dark on light, he used a sodium thiosulfate wash so that only the dark was left. It formed a permanent image of black against a metal. Of course, the image was black where the real object that had cast the image was white. John Herschel was

the first to call that a photographic "negative," for that reason.

Daguerre also managed to improve the process by beginning with a copper plate that had been covered by a thin layer of silver. He subjected this to iodine vapor which formed an exceedingly thin layer of silver iodide on the surface. This darkened comparatively rapidly in those places where light struck. The result was a "daguerreotype." The required exposure time was no more than twenty or thirty minutes, which made it practical for the imaging of landscapes, architecture, sculpture and other unmoving objects.

Daguerre revealed his process to scientific bodies on August 19, 1839, and that is usually considered the birthday of practical photography. (Niepce, poor man, had died six years too soon to see this triumph.)

The daguerreotype was quickly improved by other people who rushed into this new and exciting field. By 1841, exposure times had been reduced to a minute or so, and it became practical to make photographs of people.

The fact that daguerreotypes had to be made on pieces of metal made it an expensive process, however.

A British inventor, William Henry Fox Talbot (1800-1877), had been working on the production of permanent images independently of Daguerre. He coated his silver compounds on thin paper. Although he was making reasonably good images ("talbotypes") as early as 1835, he treated it as a personal hobby and simply amused himself with it. It was not until he heard of Daguerre's report that he hastened to present his own work to the scientific public, and by then he had lost priority.

The images on paper were not as clear as the metal-based daguerrotypes, but they were much cheaper. They had another advantage, too. The daguerreotype formed a photographic negative and that was that. Nothing else could be done with it. Light could, however, be made to shine through the paper negative, and if it shone on another photographic plate it would be reversed again to form what Herschel called a photographic "positive." Indeed, any number of positives could be made.

Talbot took advantage of this fact to publish "The Pencil of Nature" in 1844. It was the first book to include photographs. He could make as many positives out of a single negative as there were copies of the book printed, and every book could have a positive pasted on to an appropriate page that had been left blank for it.

But if paper was better than metal, glass was in some ways better than paper. Glass was rather more expensive than paper, and glass could

break (and paper could tear or burn), but glass had the great advantage of being very transparent. This meant that positives could be formed on paper with great sharpness and detail.

This was not a factor that was lost on the early photographers. Both Niepce and Daguerre would have used glass, but there seemed no way to make the silver compounds stick to the glass during the complicated process of preparing the photograph. It would either dissolve or be floated off.

It was not until 1847 that a trick was discovered that made the use of glass practical. A Frenchman, Abel Niepce de Saint-Victor, found that egg-white formed a possible base. A layer of egg-white, to which a small quantity of potassium nitrate was added, was placed on a glass plate. After the egg-white had dried a bit, a small quantity of silver nitrate solution was washed over it. This formed silver iodide, which would darken in the light. The egg-white clung firmly to the glass, and the silver iodide was held firmly in the egg-white. Photographs could be taken on glass and excellent positives could be made from it.

The trouble with the egg-white procedure, though, was that it, again, was slow, so that ten to fifteen minutes exposure was required to take the photograph.

In 1851, however, the British inventor Frederick Scott Archer (1813-1857) substituted collodion (nitrocellulose dissolved in ether) for egg-white. If silver iodide was formed in it as in the egg-white method then a photograph could be taken more rapidly than by any other process invented up to that point. The collodion-coated glass plate became the staple of the photographic art for some time to come.

Photography was still difficult, though. The coating for the glass must be prepared in advance, but not too long in advance for it could not be allowed to dry out altogether. What's more, it had to be developed on the spot after exposure, while it was still not yet dry. All the equipment required was bulky, and if photographs were taken in the open, a tent had to be set up within which developing could take place.

Even so, making use of this clumsy "wet-plate" process, the American photographer Matthew B. Brady (1823-1896) took marvelous photographs of the Union army during the Civil War.

Photography was also beginning to be used successfully for astronomic purposes. The British astronomer Warren de la Rue (1815-1889) had invented the first envelope-making machine, and now he grew interested in photography. He was one of the first to photograph the

Moon, getting a picture so sharp it could be magnified twenty-fold without becoming unacceptably fuzzy. After 1858, he was taking daily pictures of the Sun.

The Italian astronomer Pietro Angelo Secchi (1818-1878) took photographs of the Sun during various phases of an eclipse in 1851 and then set about making numerous photographs of the Moon.

The American astronomer William Cranch Bond (1789-1859) was the first person to photograph something other than the Sun or the Moon. In 1850, he photographed the star Vega, the first ever to have its picture taken.

The race was on, however, to see if, somehow, plates could be smeared with something that could be allowed to become quite dry. If such a "dry-plate" process was invented, plates could be prepared in advance at convenient times and kept for quite a long while before being used. What's more, they would not have to be developed immediately, but could be put aside for development when convenient.

Such a dry-plate process became practical in 1871, thanks to Richard Leach Maddox (1816-1902). What he did was to replace the collodion with gelatin. This could be placed on the plate and dried, and still be used, if silver compounds were formed within it. At first the development time was rather long, but in 1878, it was found that if the gelatin were heated, development was much faster, so much faster, that photography became virtually an instantaneous process.

By 1880, the dry plate process had replaced everything else.

That still left the glass plate, which was rather heavy and fragile. Was there something to substitute, something as thin as paper, but as transparent as glass, and something that was not fragile?

In 1861, the British inventor Alexander Parkes (1813-1890) had devised a method of dissolving pyroxylin (a partially-nitrated cellulose) in a mixture of alcohol and ether, with camphor added to make it softer. When this dried it formed a hard solid that was malleable on heating. Parkes did nothing with this, however.

The American inventor John Wesley Hyatt (1837-1920) improved the process and, in 1869, was manufacturing billiard balls out of it. He called the material "celluloid." It was the first synthetic plastic and could be forced through a narrow slot as it was drying so that it would form a fairly thin and transparent film that could be used for baby rattles, shirt-collars, and so on.

The American inventor George Eastman (1854-1932), anxious to get rid of the glass plates, returned to

paper at first, but then seized upon celluloid as the film on which photographic emulsions could be placed. The Eastman Company obtained a patent for such film in 1889, and for years had a virtual monopoly of it.

The use of film in place of glass meant cameras could be made small and light. What's more, with a roll of film, you could take one picture after another as the roll advanced, and the whole process of forming the image could be reduced to such simplicity that it was only necessary to push a button.

In 1888, Eastman began selling a small, simple box camera, weighing about two pounds, which he called the Kodak — an easily-memorized nonsense word. It could take a hundred pictures and then it could be sent to Rochester, where the plant was located, and the film would be developed there. The firm would return the developed photographs, together with the camera, newly-charged for another hundred.

Eastman's motto was: "You press the button; we do the rest."

This began the great era of popular photography, when it was no longer reserved for a few skilled professionals, and when one did not have to go to a professional studio for a portrait. People could snap each other readily.

To be sure, cellulose nitrate was very inflammable, and this presented a certain danger. Eastman experimented for years and, in 1924, introduced cellulose acetate, just as good a film as cellulose nitrate, and far less inflammable.

Now you know why one of the great photography firms in the world should be called "Eastman Kodak" and why I ought not to have called the process an "invention of the devil" to the president of the company.

Eastman introduced many enlightened business practices by the way: sickness benefits, retirement annuities, life insurance for his employees, long before such extras became general. He contributed over a hundred million dollars to various educational institutions and endowed dental clinics in various European cities.

In 1932, after a long and successful life, and facing a few last years in loneliness and without the prospect of further accomplishment, Eastman killed himself.

That is the end of the Eastman story, but not of photography. I'll have more to say about it next month.

SCIENCE

ISAAC ASIMOV

TRAPPING THE RAINBOW

A WEEK AGO, as I write this, I got out of a taxi and stood there for a moment, trying to get some coins back into my change purse. I realized, though, that I was still standing in the road and that other taxis were converging on me.

Unwilling to give any taxi-driver the embarrassment of crushing me under his wheels (it's my nature, always thinking of the other fellow), I stepped back in order to be out of the way. In doing so, I forgot that the curb was exactly behind me. I stubbed my heel on it, lost my balance, and fell onto the sidewalk.

I must admit that my sense of balance has deteriorated somewhat as my late youth has gotten later, but I have occasionally fallen even in my earlier youth. Ordinarily, when I do fall, I reject all help and struggle to my feet by myself even if I am in discomfort and pain — it's a matter of pride. (Of course, I couldn't do it if I had broken a bone in a fall, but I have been lucky enough never to have done that.)

This time, though, there was a great deal less alacrity about my efforts to right myself. My hat had flown off, and I presume the sight of my gray hair and white sideburns activated the feelings of a young man who had been carefully taught by his parents to be kind to the aged.

He was at my side in a moment, helping me up with his vigorous young muscles, and so far into my late youth had I now progressed that (oh, shame!) I *let* him. He handed me back my hat, and I thanked him. When he asked me, with concern, if I were hurt, I said, "Not at all," (salvaging some vestige of my pride), and then I looked at him as he smiled and walked away.

He was about thirty, I should judge, tall, slim, with a neat brown beard, and as handsome as the day. I immediately thought —

This is all wrong. This is not the

way it's supposed to be. It should have been a beautiful young woman who had tripped over the curb. My rescuer should have rescued *her*; their eyes should have met and an electricity should have sparked between them; and it should have been the beginning of a wonderful romance.

Of what use was it for him to have wasted himself on a gray-haired man in his late youth? But that's the way the world is.

In science, for instance, there is nothing as young and slim and handsome as a Nobel Prize, and sometimes it is wasted on someone not quite worthy of it. I'll give you an example in the course of continuing last month's discussion of photography, but, if you don't mind, I must take a rather sizable detour first.

My discussion, this month, begins with a Danish physician named Erasmus Bartholin (1625-1698), who was one of the gentlemen-researchers in whom the 17th Century was rife. In 1669, he received a transparent crystal from Iceland, something which was therefore called "Iceland spar," "spar" being an old Teutonic term applied to some minerals. It is actually a form of calcium carbonate.

Bartholin noticed that when he looked through the Iceland spar, objects on the other side seemed to be double. He investigated the phenomenon and found that a ray of light, passing obliquely through Iceland spar, was bent or "refracted," as it would be through other transparent materials, such as water or glass. Through Iceland spar, however, the light was refracted into *two* rays. Part of the light was refracted to a greater extent than the rest, and Bartholin called the effect "double refraction."

Just a few years earlier, the English scientist Isaac Newton (1642-1727) had studied light refraction through a prism and had found that light, in that case, was refracted to different extents, with the formation of a broad spectrum, that is, a rainbow of colors. It seemed that different colors of light combine to form what we sense as "white light," but that since each is refracted by a different amount, in passing through a prism, the white light is separated into a continuous band of colors.

What Bartholin had observed was something different. The light didn't show a steady change of refraction into a band of light, but showed a sharp separation into two rays, each of which was white.

Bartholin couldn't explain this phenomenon of double refraction. Neither could Newton, who thought that light consisted of tiny particles. Why some particles should pass

through Iceland spar with one degree of refraction, and other particles with another, he couldn't tell.

A competing theory of light was advanced by the Dutch scientist Christian Huygens (1629-1695), who felt that light consisted of longitudinal waves, as sound does, with each wave oscillating forward and back in the direction of the propagation of the light ray. Huygens couldn't explain double refraction, either.

You may think that if there was a phenomenon that could not be explained by either of the two theories of light, then those theories were *wrong* and should be instantly abandoned, and some new theory sought for. That is not quite the way science works. Both Newton's theory and Huygens' theory explained a great deal. Each, it was true, must be incomplete if double refraction didn't fit in, but it was only fair to continue studying the implications of each theory. Further investigation would probably demonstrate which of the two theories was the more nearly correct, and eventually, there would be refinements that would then include the phenomenon of double refraction. In other words, the theories were not *wrong enough* to abandon immediately (see "The Relativity of Wrong," F&SF, October 1986).

Double refraction was therefore put to one side, and, as it happened, it stayed to one side for a century and a half.

In 1808, the Paris Academy of Sciences offered a prize for anyone who could plausibly explain double refraction, and a French military engineer, Etienne Louis Malus (1775-1812), investigated the matter. Working with a crystal of Iceland spar, he found that if he turned it at certain angles, one of the two rays that emerged would disappear. Again, if he allowed the double ray of light to fall on a surface of water at a certain angle, one of the rays would pass into the water, and the other would be reflected.

Malus thought that light must exist in two forms, rather akin to the way in which magnets had a north pole and a south pole. Perhaps it was the peculiar property of Iceland spar to separate those two poles of light, where other substances did not. If one of those rays was reflected off water, while the other was absorbed, then the reflected rays would consist of only one of those poles. It would be "polarized light." Malus's theory turned out to be quite wrong, but his name lived on and we still speak of polarized light.

Malus's method of producing polarized light by reflection from a water surface was not practical. In 1828, however, a British physicist,

William Nicol (1768-1851), began with a crystal of Iceland spar. He cut it into two along the short diagonal and then stuck the halves together again by placing a thin layer of "Canadian balsam" between them as a kind of cement. The Canadian balsam layer was transparent, and its refractive ability was intermediate between those of the two rays of light that Iceland spar produced.

Light passing through the first half of the Iceland spar crystal was split in two. One of the rays was bent slightly further by the Canadian balsam and was sent to one side, while the other ray was slightly unbent and passed right through the second half without much change in direction. In other words, ordinary light entered this "Nicol prism," but polarized light emerged.

In this way, polarized light became an easily obtainable item for scientists to play with, and, indeed, it became an essential tool for the determination of molecular structures, a subject I will discuss in another essay some day.

By the time the Nicol prism was invented, the true explanation of double refraction had been advanced.

In 1801, a British physicist, Thomas Young (1773-1829), had sent rays of light through very narrow openings and showed that separate bands of light appeared where there should have been nothing but the sharply shadowed boundary of the edge of the openings. From this, he demonstrated that light rays showed the property of "interference"; that is, on some occasions, two light rays would add to each other to produce added light, while on other occasions, they would cancel each other to produce darkness.

It was difficult to see how light rays could cancel each other if they consisted of particles, but very easy to explain it if the rays consisted of waves. Young's experiments led the way, therefore, to the victory of Huygens' theory of light over that of Newton. (Actually, we have learned that light waves and all other waves have particle-properties, too; while all particles have wave-properties, too — but we needn't worry about that here.)

Young adhered to Huygens's notion of light as consisting of longitudinal waves, and that could no more explain double refraction in 1801 than it could in 1665.

In 1814, however, a French physicist, Augustin Jean Fresnel (1788-1827), made the suggestion that light consisted of *transverse* waves, waves that undulated up and down in a direction at right angles to the direction of propagation. In other words, light waves did not resemble

sound waves, but resembled rather the kind of waves we see on the surface of still water when we drop a pebble into it.

The transverse-wave theory of light explained everything that the longitudinal-wave theory of light did, and, *in addition,* explained double refraction, which otherwise could not be explained.

To see that, imagine that you are holding one end of a long rope attached to a tree in the distance. The rope passes between two of the pickets of a closely-spaced picket fence that exists half-way between you at one end of the rope and the tree on the other. Suppose you shake your end of the rope up and down so as to make waves that are analogous to Fresnel's transverse waves. The waves would pass right through the space between the pickets.

But what if you shook the rope from side to side and created horizontal waves. They would still be transverse because they would also exist at right angles to the direction of propagation. However, such horizontal waves would not pass through the space in the fence but would be stopped by the pickets on either side.

In other words, you can create waves in the rope in any direction, but only the up-and-down waves will get through the picket fence. The rope-waves would be, in this way, polarized.

In crystals, the atoms and molecules are arranged in regular array, and there are channels running both vertically and horizontally between those atoms and molecules. These channels resemble the spaces between the pickets of a fence. You can imagine light waves passing through the crystal, some waving in one direction and some in another, with all the directions at right angles to the path of propagation equally represented.

Each wave is split into two parts that are at right angles to each other, one passing through the vertical channels, the other through the horizontal ones. Each of the two have a slightly different tendency to refract so that you start with a ray of "unpolarized" light and end up with two rays of light polarized at right angles to each other. In a Nicol prism, only one of those rays gets through.

This meant there was nothing unique about Iceland spar. Polarization is actually a common phenomenon and doesn't even need crystals. Though direct sunlight is totally unpolarized, reflected sunlight is usually polarized to some extent.

For delivering a totally polarized ray of light, nothing could substitute for the Nicol prism for over a century.

There were certain organic (car-

bon-containing) crystals that would polarize light that passed through it. If one could get a crystal of such a substance large enough, it would do the job more simply and cheaply than a Nicol prism would. However, making a large enough crystal of such substances would be very difficult, and even if one succeeded, it would be far too fragile to use.

This problem interested Edwin Herbert Land (b. 1909), who was an undergraduate at Harvard College at the time. It occurred to him that it was not necessary to use a single large crystal. Many small, even microscopic, crystals would do, if they were all oriented so as to lie with their channels parallel to each other. This could be done, but how could they then be forced to maintain that position?

Land quit school in order to work on the problem, and, in 1932, when he was only 23 years old, he solved it. He lined up the crystals in a clear liquid plastic and when the plastic hardened, the crystals were held firmly in place. A thin sheet of such a plastic would act as a polarizer.

Land called the plastic sheet "Polaroid." It replaced the Nicol prism at once, but, as far as the general public was concerned, it was in sun-glasses that it found its most important use. The use of partially opaque glasses got rid of some of the glare of Sunlight, but did so at the cost of dimming vision dangerously. Polaroid allowed only part of the light to get through, and did it in such a way that the glare was reduced with greater efficiency and yet with less general dimming.

What has all this to do with photography? It made Land a rich man and gave him laboratory facilities in which research could be carried on with greater ease, so he turned his attention to photography.

All practical home photography, from the very beginning of the art right down to Land, was black-and-white. The photographic emulsions reacted in only one way to any color of light that it reacted to at all, so that all one got were light-dark combinations.

It might seem an insuperable job to photograph every different shade and tint of color separately — to trap the rainbow, so to speak — but the first indication that the problem was not as complex as it appeared came from Thomas Young, who had established the wave theory of light. In 1807, he suggested that all the various colors could be built up by different combinations of three basic colors: red, green and blue.

And, indeed, it eventually turned out that there are three kinds of receptors in the retina of the eye that are particularly sensitive to red,

green, and blue respectively. It is the combination of the extent to which each is sensitized that gives us our sensation of myriads of colors.

Young's theory was expanded and refined by the German physicist Hermann L. F. Helmholtz (1821-1894), so that the three-color system is usually known as the "Young-Helmholtz theory."

The first attempt to obtain color photographs did not, however, make use of the three-color theory. In the 1850's, the French physicist Alexandre-Edmond Bacquerel (1820-1891) made use of silver subchloride on a silver plate. He managed to get different colors developed, but it was simply a laboratory curiosity, for when the colors were exposed to light, they began to dim and soon vanished entirely. (Becquerel, though a good scientist, was far outshone by his son, who discovered radioactivity in 1896.)

The British scientist James Clerk Maxwell (1831-1879), just at about the time Becquerel was producing his colors, was insisting that the best way to achieve colored photographs was to take them in three different colors, then combine the three to get a single photograph that would trap all the colors of the rainbow.

In 1869, the first attempts in this direction were made, independently, by two Frenchmen, Charles Cros (1842-1888) and Louis Arthur du Hauron (1837-1910), but neither was able to prepare color photographs that were permanent.

The first person to prepare permanent color photographs was Gabriel Jonas Lippmann (1845-1921), who was born in Luxembourg of French parents, and who lived and worked in France. He did it in 1894, and he did *not* use the three-color process.

What he did was to place his photographic emulsion on a layer of mercury. Light passed through the emulsion, struck the mercury surface and was reflected. The reflected light passed through the emulsion again. The two kinds of light, incident and reflected, crossed each other and formed interference bands. Each different wavelength contributed differently to the interference, and the result, in the end, was a color photograph. The colors were sharp and true and the photograph was permanent.

In 1908, the Nobel prize committee met and decided to give shares of the physics prize for that year to the American inventor Thomas Alva Edison (1847-1931) and the Croatian-American inventor Nikola Tesla (1856-1943). Tesla, however, a man who was eccentric almost to the point of psychosis, would have nothing to do with Edison who (he felt, with some justice)

had cheated him. He refused to accept a prize in conjunction with his great enemy.

The Nobel committee, fearing a nasty fight and bad publicity (the Nobel Prize was only seven years old and had not yet attained that semi-divine status it now has), decided not to give the prize to either. Instead, they awarded it to Gabriel Lippmann for his invention of color photography.

I think it was a mistake. Lippmann was a good scientist of the second rank, and his scheme of color photography was extremely ingenious, but just the same the work was not of Nobel Prize quality. The trouble, you see, was that to make the photograph by his technique required relatively long exposures, and there was no way of making copies. Consequently, Lippmann's method was never used by others and it had no relationship to the practical color photography that eventually came to pass. And there you have the connection with my initial anecdote of the handsome young man who helped a gray-haired old man to his feet, when by all the laws of romance he should have helped a beautiful young woman.

What I think the Nobel Prize committee should have done was to have picked either Edison or Tesla, since each was worth it. And I would have picked Tesla. Tesla may have been a somewhat nutty genius, but Edison was a somewhat ruthless one, and I prefer nuttiness.

The first practical three-color process of color photography was advanced in 1907 by two French photographers, the brothers Auguste Lumiere (1862-1954) and Louis Lumiere (1864-1948). Their last name, by the way, is the French word for "lamp," so it was only appropriate for them to work with light.

What they did was to place under the photographic emulsion a film containing three dyes: red, yellow, and blue. Different wavelengths of light reacted with the film in different ways, here and there, according to the nature of the light reaching that part of the film. In the end, colors formed on the film that more or less duplicated those of the scene being photographed. This is called "additive color" because the effect of the different dyes is added to the light after it passes through the emulsion.

Additive color, however, did not quite reproduce the colors of the scene being photographed in true enough fashion. Nor were the pictures sharp enough.

In the 1930's, the people at Kodak worked out an alternate method of color photography, in which films with colored dyes were placed in *front* of the photographic emulsion.

Each dye subtracted certain wavelengths from a particular region of light as it reached the emulsion. The final result is the "subtractive color" method, and this gave true colors and sharper images, so that it replaced the additive color method almost at once.

The color photographs, whether additive or subtractive, were at first produced on transparent film. One had to look at them through a hand-held viewer pointed at some light source; or one had to project them onto a screen. Projection onto a screen made it practical to have motion pictures in color, something that was pioneered in a Disney short in 1932, and came to flower in the feature movie "Becky Sharp" in 1935.

It was not till 1942 that a practical process was invented whereby the color could be transferred onto paper so that a person could hold something that is exactly like an old black-and-white photograph except that it is in full color.

Even then, the fact that World War II was on slowed down the rate at which such color-prints entered the general market, and it was not till the 1950's that they became commonly available.

In 1963, Land, who had devised the self-developing black-and-white print, modified the procedure to include the appropriate dyes in the camera (making use of new and simplified theories of his own in place of the old Young-Helmholtz three-color theory). As a result, people were able to point their camera, press the button, and, within a minute, have a developed color photograph.

Even this is not enough. Ordinary photographs, even the most advanced instant-color ones, are only two-dimensional cross-sections of a three-dimensional scene. In 1947, however, the Hungarian-British physicist Dennis Gabor (1900-1979) thought of a way of adding a third dimension.

Suppose that a beam of light is split in two. One part strikes an object and is reflected with all the irregularities that this object would impose on it. The second part is reflected from a mirror and gains no irregularities. The two parts meet at the photographic film, and the interference pattern is photographed. If light is then allowed to pass through the film, it takes on the interference characteristics and produces a three-dimensional image in mid-air, one that is of startling realism and and can be viewed, to some extent, from different angles.

This is called "holography," because it gives the whole image and not just a two-dimensional projection.

Gabor supplied the theory, but holography could not easily be put into practice until laser beams of coherent light became available. In 1965, two scientists, Emmet N. Leith and Juris Upatnieks, were able to produce the first holographs. By 1971, holography had done enough to make it seem warranted to award Gabor a Nobel Prize for physics.

Despite that, however, holography is still in the hands of specialists and experts. Techniques for making it accessible to the general public, so that holographic images can be produced as easily and as satisfactorily as ordinary photographs, do not yet exist, and may not exist for quite some time.

Still, even holography is not enough. Any image, whether on a photograph or a holograph, whether two-dimensional or three-dimensional, catches a scene as it is only during some particular instant.

What we need is to add the fourth dimension of time, so that we can see the image moving.

If we didn't know better, we would think that this, finally, is an impossible requirement. Once it was found that silver salts break down and blacken in the presence of light, photography became conceivable in minds with sufficient imagination; and since white light is composed of different colors, color photography becomes conceivable, too. And since the existence of three dimensional images at the foci of concave parabolic mirrors is known, even holography is conceivable.

But pictures that move! Surely that is too much.

And yet it was a requirement that was surprisingly easy to meet. In fact, pictures could be made to move well before they could be given color.

I will, therefore, take up the subject of pictures that move next month.

SCIENCE

ISAAC ASIMOV

THE ILLUSION OF MOTION

I AM A professional speaker, and one of the things I have had to do in the course of this activity of mine has been to learn how to tell jokes. (Fortunately, as in the case of writing, I had a natural aptitude for it, so I managed.)

One of the great satisfactions in telling a joke is to milk it, that is, to use its conclusion as the starting point for another comment, which, if you are lucky, gets another laugh, and, if you are very lucky, gets a bigger laugh than the first time.

This happened to me last week, when I told the following story at the Dutch Treat Club, which, as president, I routinely emcee.

"According to a possibly apocryphal story that I have heard," I said, "the great Shakespearian scholar, George Lyman Kittredge, retired from his professorial position at Harvard in the fullness of his honored old age, and finding time hanging heavy on his hands, took on the duties of teaching Shakespeare at a small women's college.

"Mrs. Kittredge served tea to some of her new friends one afternoon, and one of them said diffidently, 'Tell me, Mrs. Kittredge, does it make you nervous to have the professor in the constant company of so many attractive young women?'

"Mrs. Kittredge raised her eyebrows, and said, 'Are you implying that the professor would misbehave with one or more of them? I would have you know that the professor is too fine a gentleman to act so; too ethical, too decent, too aware of his duty to me, and, most of all — *most* of all — too old.'"

At this, there was a general laugh of satisfactory proportions from the audience, and I waited for it to die down. Then, with a look of as much pathos as I could squeeze onto my face, I said, mournfully, "Ah, yes, there was a time when I, too, laughed at that joke."

And the hard-hearted audience laughed twice as hard at that.

Well, it strikes me now that I sometimes milk my essays in this magazine as well. I start out to write a simple essay on photography, then find I must write a second on polarization and on color photography and now I must write a third on photographs that give the illusion of motion.

What makes the illusion of motion is that the brain does not handle vision instantaneously. A pattern of light-and-color is imprinted on the retina, which transmits it to the brain. The brain hangs on to that pattern for a fraction of a second.

If, in the interval, a slight change has taken place in the scene and a second slightly different message reaches the brain, the brain handles it before the first has died out. It senses a kind of flow from the first to the second. If such slight changes continue progressively, the brain interprets the continuous flow of change as motion.

This phenomenon of "persistence of vision" was noted even in ancient times. About 130, the Greek scientist Claudius Ptolemy (100-170), working in Egypt, wrote his great summary of Greek astronomy. In the book he pointed out, in passing, that if a portion of a disk is colored, and then the disk is whirled, the entire disk seems to be colored. This is because the brain doesn't let go of the sensation before the disk has made a complete turn and supplied it again.

But, for that matter, you don't need the ancients to tell you this. You can observe it for yourself. I remember, as a child, sitting out on the stoop of a building on a hot evening, along with others who were doing the same all up and down the block. (There was no air-conditioning in those days.) In order to keep the mosquitoes off, so a fond superstition held, it was necessary to set a thin stick of citronella alight. It glowed at the tip and slowly, slowly smoldered, producing a smoke or an odor that mosquitoes were supposed to find unpleasant.

I found (as I assume everyone did) that when I moved the punk rapidly, the lighted edge made geometric figures — circles, ovals, and others. This was because the brain could not sense an individual point of light first here, then there, then further still. It blended all the points together into a curve.

Suppose, then, that there was a series of drawings, each one showing an object that changed its shape slightly and progressively. It might be a human figure, with arms and legs changing position in the fashion that they would if it were

in motion. If these drawings are placed one on top of the other and the edges are flipped so that you see them in rapid succession, your brain blends the sensations, and the result is that the pictures yield the illusion of a human being walking.

The first person to make use of persistence of vision in some practical way was an English doctor, J.A. Paris. In 1826, he prepared a cardboard disk on one side of which he drew the trunk and branches of a tree, with no foliage. On the other side he drew foliage in the proper position, but with no trunk or branches. The cardboard disk was suspended from silk threads in such a way that if the threads were rapidly turned between thumb and forefinger, the cardboard spun even more rapidly. What you saw, then, was both sides of the card simultaneously, for one side had not faded before the other had come into view. You saw a tree complete with foliage. Paris called it a "thaumatrope," which is Greek for "wonder-turner."

Paris's device was only good as a parlor trick, to be shown now and then to the momentary amusement of an audience, but it did point the way to the production of many drawings and motion by flip. I remember reading a book on atomic physics in my teen-age years, in which borders of successive pages had drawings of electrons circling a nucleus and leaving an orbital train behind. If you flipped the pages, you could not only see the electrons moving, but you could see their orbit precessing. There were other such visions, too, and I think I spent almost as much time flipping the pages as reading the book.

Actually, Paris's device was followed by something more sophisticated than flipping pages. In 1832, a Belgian physicist, Joseph A. F. Plateau (1801-1833), prepared a cylinder with slots in the sides, so that, as it whirled, you could see through first one slot, then another in rapid succession. In fact, sight seemed a little hazy, but continuous, for the brain did not let go of the sight through one slot before the next appeared.

Inside the cylinder was another cylinder on which were drawn figures that changed progressively, and a mirror was so arranged that each figure was seen through the slot facing the viewer, one after the other. When the cylinder was spun, it seemed to the viewer that he was watching a moving object. Of course, there was only one flow of movement that was completed in one spin of the cylinder, and thereafter it repeated itself endlessly, but it was still an amazing phenomenon to those who viewed such a

thing for the first time.

Within two years, a British mathematician, William George Horner (1786-1837), had modified the device so that a number of people could watch at the same time. He also made the cylinder of changing drawings more elaborate. He called the device the "zoetrope" (Greek for "life-turning," or "wheel of life" because motion is so closely associated with living things).

In 1853, an Austrian artillery officer, Baron F. von Uchatius (1811-1881), tried to teach parade maneuvers by use of successive drawings. He worked out a way to project the drawings on a screen, one after the other, and could show up to 30 seconds of maneuvers in this way, with a whole company of soldiers watching. Illusion of motion for 30 seconds remained a record for over forty years.

By von Uchatius' time, however, photography had come into being (see "The Invention of the Devil," November 1990). It did not take much to see that if, somehow, one could take very rapid photographs, one after the other, of a moving object, and if those photographs were shown, one after the other, with great rapidity, the illusion of motion could appear with much greater fidelity than anything that could be done with drawings.

The necessary techniques for rapid photography and rapid projection had to be developed, however, and that took half a century.

The first person to show the importance of the study of motion through photographs in an important and significant way was the British-American photographer Eadweard (sic) Muybridge (1830-1904), who had migrated to the United States to participate in the California gold rush.

In those days, no one really knew the details of how a horse ran. If you look at rocking horses, you will see the front legs extended forward and the hind legs extended backward, as though a galloping horse progressed by leaps, as a jackrabbit does. This may have come about because horses were easier to carve in this fashion, but if you look at old prints of fox hunts, you will find the horses drawn just as though they were rocking horses. Needless to say, no horse ever ran in that fashion.

Even those close observers who noticed that a galloping horse moved each leg independently could not make out the exact details of the motion because those legs were moving too rapidly.

Leland Stanford (1824-1893), who had been governor of California from 1861 to 1863, was a millionaire who bred and raced horses. He maintained that at some point in a

horse's gallop, all four legs were off the ground. A rival horse-breeder was convinced that this could not be so, and the two wagered $25,000 (a staggering sum in those days) on their respective viewpoints. The only trouble was that there seemed to be no way of settling the bet. No amount of watching horses gallop could produce unequivocal evidence one way or the other.

In 1872, then, Stanford hired Muybridge to settle the matter. Muybridge stretched twelve strings across the race track, with one end of each string attached to a different camera ready to go. A galloping horse broke each string in succession, activating each camera in succession, and taking twelve photographs. The photographs were then examined. One of them showed all four legs of the horse off the ground and Stanford collected his $25,000.

This made it quite plain that photography was the route whereby motion could best be studied, and Muybridge spent years taking more and more photographs of moving objects at shorter intervals.

A French photographer, Etienne Jules Marey (1830-1904), was also working on the project. He and Muybridge corresponded with each other and kept each other apprised of their own progress. Marey was the first to manage to produce (with a single camera) enough photographs, closely enough spaced, to produce the illusion of motion in the same fashion that had been done with drawings for half a century. Marey accomplished the feat in 1882, and this was the fundamental beginning of what we now call "motion pictures." It was a very primitive beginning, for Marey achieved only a few seconds of motion.

What was needed now was a great many photographs, taken at very sort intervals, and developed on some transparent medium. The photographs could be developed on a long strip of such a transparent medium, and this could be passed before a rapidly flickering light which could project first one, then the next, then the next, onto a screen at sub-second intervals — one with each flicker of light.

The technique was easy to visualize, but working out the mechanics was not easy. Through the 1890s, a number of inventors sweated over the problem; and, by the end of the decade, motion pictures were in existence, but it is hard to point to any one single man and claim him as the inventor.

Most of the very early work was done in France, and the Lumiere brothers (whom I mentioned in last month's essay as the founders, later on, of color photography) improved

the system of projection and established the speed at which photographs were flashed on the screen at 16 per second (the speed still used today). They were the first, in 1895, to project life-size examples of the photographic illusion of motion. This is perhaps the closest we can come to the invention of the motion picture as we know it now.

The Lumieres, in 1896, called the new art "cinematography," from the Greek work "kinema," meaning "movement." The word is frequently shortened to "cinema." (When I was young, I sometimes attended a local movie house called the "Kinema." When I grew older and learned the word "cinema," I assumed that the owners of the local moviehouse, being ignorant, had misspelled the word. When I grew still older, I realized the local moviehouse was completely correct, and that "cinema" is simply the Latin spelling, as distorted in pronunciation by the French soft "c".)

There are all kinds of other names for the art: "moving pictures," "motion pictures," "photoplays," though the usual term used by Americans is simply "the movies." It is also possible to call it, more or less poetically, the "silver screen," or, in memory of the flicker existing in early motion pictures, before further improvements made photographic transitions smooth, the "flicks."

In the United States, Thomas Alva Edison (1847-1931) used strips of celluloid film on which to develop photographs and was the first to place perforations at the sides so that the teeth of gears could engage them and pull the film along at an appropriate speed. He patented this in 1897, and this is the foundation of the American assumption that Edison invented the motion picture. His advance was extremely important, but the Lumieres beat him to the punch.

The earliest motion pictures produced by the pioneers of the 1890's were simply brief skits of, say, a man sneezing, or people walking. The most famous of these early bits was called "The Kiss." Produced in 1896, it merely showed a man smoothing his mustache, looking lustful, and then planting a smackeroo on a woman's lips. It undoubtedly shocked the pious and delighted everyone else.

A French cinematographer, George Meleis (1861-1938), was the first to understand that motion pictures didn't have to be realistic; that one could do tricks with the camera, slowing it or speeding it to produce motions at an unnatural rate. He also realized that by splicing film, he could make objects appear suddenly, or transform one

thing into another. In short, he showed that motion pictures were not simply a representation of nature but were a completely new art-form in their own right. In 1902, he made the first science fiction movie, "A Trip to the Moon," in which a rocket ship is shown hitting the man in the Moon right in the eye.

Another French cinematographer, Ferdinand Zecca (1864-1947), applied Melies' trickery to the filming of chases in fast motion. We have all seen this sort of amusing thing in early comedies, and we can see it even today in the Benny Hill television show.

It always induces laughter to see the laws of nature bent. I don't know who was the first person to run a movie film backward, but it defies the second law of thermodynamics to see a broken vase reassemble itself, or to see a body swoop up from a pool, and balance, perfectly dry, on a diving board.

In the United States, there was a slow start, because Edison, a contentious individual who tried to claim as much for himself as possible, sued everyone in sight, so that advances were lost in litigation.

In 1903, however, the American cinematographer Edwin S. Porter (1870-1941), while working for Edison, was the first to use films to tell a story. The most famous example of this was "The Great Train Robbery" produced in 1903. It proved to be very popular and established movies as story-telling devices.

Soon the movies were commercialized as places were established where anyone with a coin could see a show. The admission in the United States was usually a nickel, so that the movie houses were called "nickelodeons" ("odeon" is the Greek word for "theater"). The first American nickelodeon made its appearance in Pittsburgh in 1905. Soon they existed in every large city in Europe and the United States.

Movies came of age with the American cinematographer David Wark Griffith (1875-1948). He invented virtually all the techniques that have been used in movies ever since — the closeup, the fadeout, the cross-cutting, and so on.

His most famous film was "The Birth of a Nation," produced in 1913. It was the first full-length film, and the first one that we of today would recognize as a motion picture. However, the film glorified the Ku Klux Klan and vilified Blacks. Griffith, stung by the violent criticism the picture attracted because of its bigotry, went on to produce "Intolerance" in 1916, in which he

inveighed against bigotry. His techniques in this film were smoother than in the earlier one.

Griffith's most influential change, however, was probably unintentional, and it was the introduction of the "star system." In the early movies, the actors were not identified. However, the movies were the first art-form to reach millions of people more or less simultaneously, and there was an outpouring of interest in particular actors and demands to see more of them. It was clear that pictures would be successful not through their titles or their plots, but chiefly through the appearance of some beloved actor or actress. Emphasis, therefore, shifted from the movie itself to the "stars" that were to be found in it.

The first actor to become a star was Mary Pickford (1893-1979), who became known as "America's Sweetheart." Another was Lillian Gish (b.1896), who starred in Griffith's early movies and who is still alive today. Griffith also introduced Douglas Fairbanks (1883-1939) in 1915, and he became the first of the great swashbucklers.

In the meanwhile, a disciple of Griffith, Mack Sennett (1880-1960), was developing the slapstick comedy. He made a thousand short comedies, many featuring the "Keystone Kops," and introduced all the great comics of the period, including the greatest comic of all time (in my opinion), Charles Spencer ("Charlie") Chaplin (1889-1971). Sennett produced the first full-length comedy, "Tillie's Punctured Romance" in 1914. It starred Charlie Chaplin and Marie Dressler (1869-1934).

The first serial, produced in 1915, was "The Perils of Pauline," in which each episode ended in a cliff-hanger designed to draw the public back one week later for the next episode.

The 1920s were the golden age of the early motion pictures. Such stars as Rudolph Valentino (1895-1926), Clara Bow (1905-1965), John Gilbert (1895-1936) and Greta Garbo (1905-1990) reached new heights of adulation. Cecil Blount DeMille (1881-1959) produced "spectacles" that were more remarkable for their elaborate hokum than for quality, as in "The Ten Commandments" produced in 1923. There were great foreign films, too, including, "The Cabinet of Dr. Caligari," produced in Germany in 1919, and "Potemkin," produced in the Soviet Union in 1925.

The early movies were silent and were performed in pantomine, with occasional intrusive slides featuring short bits of dialog or editorial comment. The silent for-

mat was an art-form in itself, with the accent on exaggerated facial expression while the camera was cleverly used for non-verbal communication.

There was, on the one hand, an almost comical artificiality about it, and yet, once you allowed for the limitations of silence, there was something refreshing about it. It did away with the endless talking of ordinary theatrical drama and encouraged the development of novel and fascinating visual techniques.

Nevertheless, the movies could not be viewed in absolute silence. That was too great a departure from our noisy world. The films came to be accompanied by someone playing the piano or the organ, who adjusted the music to the mood of the picture. (I have a friend who specializes in early movies who says that a silent picture must never be shown truly silent; that they were made with musical accompaniment in mind.)

Naturally, there were attempts to add sound to the film directly, to have the actors talk. Sound could easily be recorded by this time, since Edison had invented the phonograph in 1877. The trick was to run the film and at the same time to record and broadcast the dialog and other sound effects, keeping photography and sound in exact synchronization.

The introduction of sound into "The Jazz Singer," produced in 1927 and starring Al Jolson (1886-1950), created a sensation, even though the technique was very primitive. At almost a stroke, motion pictures became "talking pictures" or "talkies." Eventually, the sound track was impressed visually on the film itself so that there was no chance of any loss of synchronization.

By 1929, silent movies were dead, only 16 years after "The Birth of a Nation." It was the first major art-form really to die. It was a loss in its way, for the "talkies," by reverting to realism, wiped out a whole system of increasingly subtle and complex forms of visual communication.

Movies had not, however, entirely brought about the replacement of drawings that mimicked motion. It was still possible to produce "animated cartoons." These were exceedingly popular, especially with the young, for they made possible humorous fantasies that were difficult, or even impossible, with photographs. These, too, were converted to sound. The first animated cartoon with sound was "Steamboat Willie" produced by Walter Elias ("Walt") Disney (1901-1966) in 1928. This was the first cartoon to feature Mickey Mouse, who was eventually to sweep the world with a fame

unknown to merely living individuals.

For the first forty years of motion picture history, the films, whether silent or talking, were black-and-white. The use of black-and-white developed into an art-form of its own and was used so subtly and effectively that such movies were completely satisfactory, and the absence of color was not noted. To this day when I see early talking pictures (notably the Fred Astaire/-Ginger Rogers pictures) I do not miss color at all.

Nevertheless, once color photography came into use, it was inevitable that it be applied to motion pictures, too. "Technicolor" was invented, in which three separate films in red, green, and blue were combined to produce full color on the screen. This was first used in a Disney animated cartoon, "Flowers and Trees," produced in 1932, and in a full-length picture for the first time in 1935, in "Becky Sharp," starring Miriam Hopkins (1902-1972).

The advent of color was not quite as overwhelming as the coming of sound had been. The public marvelled at the color but did not go wild with demand for it. Therefore, since the Technicolor process was extremely expensive, both for the producers and the theaters, there was no great rush to it. Black-and-white pictures continued to be made, some even to this day.

However, color systems that were cheaper than Technicolor came into use, though not with entirely happy results. When early color pictures are viewed now, those in Technicolor are as fresh and bright as the day they were printed, while other forms of color can fade and distort badly.

Movies in color came into their own only after color television appeared on the screen. Television was a great market for old movies, and since it had color, it did not wish to use black-and-white films except at 3 A.M. perhaps. Motion pictures were therefore forced to go into color to preserve their television market.

There are, of course, black-and-white classics that are well worth viewing over and over again, and there is a movement, therefore, to "colorize" them and make them suitable for television. This, however, kills the subtlety of the black-and-white and substitutes something garish and unpleasant. Many actors are fighting desperately to outlaw colorizing but I suppose they will lose. The motion picture industry carries the American preference for money over quality to an absolute extreme.

Motion pictures moved on to

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other devices that were designed to counter the growing popularity of television in the home. They made use of a wide screen to give a feeling of amplitude to theater showings that could not be duplicated on the small screen of the television set. They expanded this to the extreme of "Cinerama," which used three separate and synchronized screens. They also introduced three-dimensional effects. These were not, on the whole, successful.

Motion pictures then permeated themselves with sex and violence on the assumption that the public would have to go to theaters to see them since they would never be shown in the sanctity of the family living room. However, these films have moved into television, too, especially since cassettes can now be bought for private viewing.

So I suppose the milking of essays must continue, for now I will have to talk about television next month.

SCIENCE

ISAAC ASIMOV

DOWN THE ELECTRON STREAM

ON MAY 31, 1990, I had lunch at the Soviet Embassy in Washington, D.C., along with some forty other Americans and a number of Soviet citizens as well. Mikhail Gorbachev, President of the Soviet Union, was the host.

Ray Bradbury was the only other science fiction writer present, and we were there, I gathered, because our books were popular in the Soviet Union. President Gorbachev mentioned us specifically in the talk he gave, and Ray and I were both terribly pleased that we were the occasion for this plug for science fiction.

The lunch was scheduled to be over at 2:30 P.M., and my dear wife, Janet, was waiting for me downstairs in the Embassy. (There was no room for mates at the lunch, but the Embassy people took good care of her.) When 2:45 P.M. came and the luncheon was still going strong, I felt I could not remain away from Janet any longer, and I was well aware, in addition, that I had a train to make. Consequently, I whispered my good-byes and left quietly.

Since I was the first person out of the building, I was leaped upon by a horde of reporters who asked the questions you might expect. ("What was Gorbachev like?" "What did he say?")

One question amused me particularly, however. It was, "Why on Earth would Gorbachev want to see you people?"

The proper answer would have been: "Search me! Why don't you ask him?"

That, however, would not have given satisfaction. Instead, I said, "I suppose Gorbachev felt that a politician should not spend his time speaking only with other politicians."

The reporters scribbled it down but, as far as I know, that statement wasn't used in any of the reports on the event.

My reason for saying it was a very simple one. It is merely an extension of something that I have believed for many years — that scientists should not speak only with other scientists.

It seems to me extremely important that scientists should spend an adequate portion of their time speaking to non-scientists, trying to get across to the wider public what science means, what scientists have done and are doing and, just as important, perhaps gathering what the wider public thinks of science and what its hopes and fears of science and technology might be.

It is because of this belief of mine that I have spent so large a portion of my life writing and speaking about science and technology to the general public. And it is the essay series in this magazine, which has been continuing now, without a break, for a third of a century, that I consider my most important contribution in this direction.

So let us continue—

In my last three essays I have discussed the production, by chemical means, of, first, images, then colored images, and finally moving images. Now we pass on to the electronic production of images.

In the July 1982 issue of F&SF, in my essay, "The Three Who Died Too Soon," I described the discovery, in 1888, of very long-wave radiation by the German physicist Heinrich Rudolph Hertz (1857-1894).

The radiation was called "Hertzian waves" to begin with. They were part of the family of electromagnetic radiations, of which visible light is the best-known member. Hertzian waves are a million and more times as long as light-waves, but except for that they are light-like in character.

It didn't take long for people to realize that radio waves could be made to send messages, just as light waves could. You could send a message in Morse code by blinking a light on and off in long and short intervals, and you could do the same with Hertzian waves.

Hertzian waves had the advantage of having wavelengths so long they could go through fog and either through or around obstacles, which light could not do. Hertzian waves had the disadvantage, however, of being difficult to detect. After all, we have eyes with which to see light, but no sense organ that would pick up Hertzian waves.

Hertz had both produced and detected the radio waves by the use of a wire loop with a small airgap. In one of these, an alternating current sent sparks across the gap, creating Hertzian waves; and these in turn, produced sparks, jumping the gap in the other loop, or detector, to

which no electric source was attached.

A French physicist, Edouard Eugene Branly (1844-1940), improved on the detector, in 1890, by using a glass tube filled with metal filings to which wires and a battery were attached. When Hertzian waves fell on the tube, they pushed the powder together, making it more compact and coherent, and increasing its electrical conductivity so that a current flashed through it from the battery. With the use of this "coherer," Branly could detect Hertzian waves at a distance of 135 meters.

The device was improved by the British physicist Oliver Joseph Lodge (1851-1940). He succeeded in detecting signals at a distance of 800 meters and could send messages in Morse code by turning the Hertzian waves on and off.

This opened the way to sending messages by radiation alone, instead of by electric currents across wires as in the case of the telegraph, which had been invented a half-century earlier. The new method therefore came to be called "wireless telegraphy," a phrase the British eventually shortened simply to "wireless."

Since radiation, rather than an electric current, was used to transmit the messages, it could also be called "radiotelegraphy," which Americans eventually shortened simply to "radio." As a result, Hertzian waves came to be called "radio waves."

Lodge's device still came under the heading of a laboratory curiosity, but, in 1894, an Italian electrical engineer, Guglielmo Marconi (1874-1937), became interested in the matter.

He found that he could send out stronger signals and receive them over longer distances if he grounded the generator and receiver and added a wire that reached up into the air. (The latter was called an "antenna" because it resembled an insect's feeler.)

A Russian physicist, Alexander Stepanovich Popov (1859-1906), used an antenna even earlier, but he was interested chiefly in the scientific investigation of lightning, while Marconi turned to the commercialization of the technique, so it is Marconi who gets (and should get) the credit for what followed.

Using his antennas, Marconi could, in 1895, send and detect radio waves across a distance of 3 kilometers. In 1896, he went to Great Britain (his mother was Irish, by the way) and sent a signal across a distance of 14 kilometers. He then applied for, and obtained, the first patent in the history of radio.

In 1897, again in Italy, he sent a signal from land to a ship nearly 20 kilometers away, and, in 1898, back

in Great Britain, he detected radio waves at a distance of nearly 30 kilometers.

By 1898, moreover, he was beginning to make his system commercial. The British physicist Lord Kelvin (1824-1907) paid to send a "Marconigram" to another British physicist, George Gabriel Stokes (1819-1903). That was the first commercial radio message. Marconi also used his signals to report the yacht races at Kingstown Regatta that year.

Then, in 1901, came a climax. Although radio waves travel in straight lines, Marconi had already convinced himself that they would follow the curve of the Earth's sphere. (They do this, it was eventually discovered, by bouncing off layers of electrically-charged atoms in the upper atmosphere.)

He therefore sent a message — the Morse-code signal for the letter "S" — from the southwestern tip of England, using balloons to lift the antenna as high as possible. On December 12, 1901, he succeeded in having the signal received in Newfoundland, across the width of the Atlantic Ocean, and that date is usually taken as the birth of radio.

In 1904, a demonstration of radio operation was a big hit at the St. Louis World's Fair, and, in 1909, Marconi received a share of the Nobel Prize for physics.

So far, radio was still only a Morse-code device. A Canadian-American physicist, Reginald Aubrey Fessenden (1866-1932), developed a new and better way of generating radio waves, involving high-frequency alternating currents. He also worked out a way of making the radio waves increase and decrease in height (or "amplitude") in such a way that the line marking out the heights of successive radio-wave peaks marked out the irregularities of a particular sound-wave. This was called "amplitude modulation" and was abbreviated "AM."

Sound waves could be converted into modulated radio waves that could be sent out. When these were received, they could be converted back into the original sound waves. As a result, radio messages could consist of words and music. The first such message, sending out music from a transmitter on the Massachusetts coast, was picked up and carried on December 24, 1906.

Radio signals were still terribly weak, however, and detecting them was chancy and required expert manipulation.

In 1883, however, Edison, trying to lengthen the lifetime of the electric light bulbs he had invented seven years earlier, sealed a metal wire into the light bulb near the hot filament. That did nothing to

lengthen the filament's lifetime, but, to Edison's surprise, electricity followed from the hot filament to the metal wire, across the vacuum gap. This was called the "Edison effect."

After the electron was discovered in 1895, the Edison effect was explained. In experiments conducted between 1900 and 1903, the British physicist Owen Willans Richardson (1879-1959) showed that the electricity flowed because a stream of electrons boiled out of the hot filament. In 1928, when the consequences of this discovery had become plain, Richardson received a Nobel Prize in physics.

Once a stream of electrons was shown to exist, the problem was to control the flow. It could, as it turned out, be controlled far more quickly and delicately than could an electric current through a wire. The use of streams of electrons in place of electric currents is called "electronics," and devices that made use of such streams were "electronic devices."

The first electronic device was produced, in 1904, by a British electrical engineer, John Ambrose Fleming (1849-1945). He surrounded the filament with a thin cylindrical metal plate. He found that electrons boiled out of the hot filament only when the plate carried a positive electric charge that attracted the electrons out of the filament. When the plate carried a negative-charge, it repelled the electrons and kept them from emerging from the filament.

Fleming made use of an alternating current (the current flowing in each direction in rapid alternation), and this had the plate alternate between negative and positive charge. There would be an intermittent burst of electrons each time the plate was positive. This meant that though an alternating current flowed into the evacuated device, an intermittent direct current (in only one direction) flowed out. The conversion of alternating to direct current is "rectification," so the device is a "rectifier."

Fleming called it a "valve," because it allowed electricity to flow through it in one direction only. In the United States it came to be called a "tube" for some reason. Scientists call it a "diode," for it has two electrodes, the filament and the plate.

The American inventor Lee De Forest (1873-1961) added a refinement to Fleming's tube in 1906. He inserted a perforated plate, or "grid," between the filament and the solid plate, making it a "triode." The grid was closer to the filament than the plate was, and slight changes in the intensity of a positive charge upon it could result in great changes in

the intensity of the electron stream.

If, then, the grid receives a varying electric current such as that produced by an amplitude-modulated radio wave, it produces a much stronger current that exactly imitates the modulation. In short, the triode serves as an "amplifier," strengthening a weak current without distorting its characteristics.

Such triodes (and numerous modifications thereof) could be used in devices that sent out and received radio messages, making the task much simpler and more nearly within the range of ability of people who were not expert radio engineers. As a result, the triode came to be called a "radio tube," and they were indispensable adjuncts to radio sets for nearly half a century.

In 1910, De Forest was using his tube-amplified radio system to transmit the singing of the great tenor Enrico Caruso (1873-1921), and, in 1916, he established a radio station and was broadcasting news. When he first tried to finance his invention, by the way, so unbelievable did his claims seem to be that he was placed under arrest for using the mails to defraud. In the end, however, he sold the patent rights to his amplifier to American Telephone and Telegraph for $390,000.

Even with radio tubes, however, it was still tricky to try to tune radios to receive a particular wavelength, and once found, those wavelengths were easy to lose. Trying to receive a broadcast was still an adventure, therefore, and a strain on anyone's patience.

During World War I, however, an American electrical engineer, Edwin Howard Armstrong (1890-1954), was trying to detect enemy airplanes by sound-waves. It seemed to him that it might be more sensitive and efficient to detect the electromagnetic waves set up by the planes' ignition systems. Those waves were too high in frequency (that is, too short in wavelength) to be received easily, so Armstrong devised a circuit that lowered the frequency and then amplified it. He named it a "superheterodyne receiver."

Actually, this was developed too late to play a role in the war itself, but it could be put to use in radio reception. With the addition of a superheterodyne receiver, radios could be tuned very easily by the turn of a dial. Now, at last, radios became popular with the general public, to the point, indeed, where radio sets became a common article of living room furniture.

In 1921, regular radio programs were begun by a station in Pittsburgh, and, thereafter, other stations were set up in rapid succession. By 1924, presidential election returns were broadcast by radio, and by the

end of the decade, programs featuring Amos and Andy and the crooner Rudy Vallee became national obsessions.

There remained the problem of static. Thunderstorms and electrical appliances modulate the amplitude of the carrier waves that transmit messages from broadcasting station to receiver, and do so in random fashion. The result is an unpleasant noise that interferes with the words and music we are trying to hear.

In 1935, Armstrong worked out a system whereby the carrier was modulated not by amplitude (loudness) but by frequency (pitch). This "frequency modulation" of "FM" worked just as well as "AM" did and was not interfered with by those things that were a source of static in amplitude modulation.

Radio gives us only sound, of course. Is it possible that we can also get visual images by electronic means?

The principle of transmitting photographs or any visual image was clear enough even without the use of electron streams. A beam of light is allowed to pass through a photographic film and to fall on a photosensitive plate behind. The beam of light scans the photograph systematically and reaches the plate, being brighter or dimmer, depending on what portion of the photograph it passes through.

The photosensitive plate might contain a coating of the element selenium, which, in 1873, had been found to have its electrical conductivity affected by light. In the presence of light, it is much more conductive than in darkness, and the stronger the light the greater the conductivity.

As the light scan progresses across the photosensitive plate, it is therefore transformed into a varying electric current that mimics the changing brightness of the scan. The varying electric current is transmitted along a wire and, at the other end, can be reconverted into the original pattern of light and dark. In this way, a photograph is transmitted by wire, and the first such "wirephoto" was transmitted between London and Paris in 1907.

By that time, a Russian scientist, Boris Rosing, suggested the obvious — that if a series of images were scanned and sent over the wire, the images could be made to give the illusion of motion, as was true in motion pictures, which I described last month. In that way, you could transmit motion as it was happening, and you would have what came to be called "television."

It was easy to suggest it, but the trick was to find a method of scanning that was sufficiently delicate and rapid. The usual method for

producing wirephotos in those early days was to have little holes arranged in a spiral pattern on a plate. As the plate spun, light passed through the holes and scanned the photograph systematically. That worked well enough for wirephotos, but it would never have been adequate for even the most primitive form of television.

There was, however, something else in the works. Scientists had been studying cathode-ray tubes as long before as the 1880s. The cathode-ray tube is an evacuated device that contains two electrodes. A stream of electrons (or "cathode-ray particles," as they were called before it was understood what electrons were) poured through the vacuum from the negative electrode when it was heated. The stream could be made to hit the glass at the other end, and the energy of the motion of the particles was converted into light. A spot of light appeared where the electrons hit the glass.

If the cathode-ray tube were subjected to an electromagnetic field, the stream of electrons (which carried a negative electric charge) was deflected and the spot of light changed position.

In 1897, a German physicist, Karl Ferdinand Braun (1850-1918), modified a cathode-ray tube in such a way that the particles could be easily affected by an electromagnetic field of varying intensity. The spot of light therefore moved up and down and left to right, in such a way as to visualize the variation in intensity in the form of a wave. He called this an "oscillograph."

In 1908, therefore, a British electrical engineer, A. A. Campbell Swinton, suggested that an oscillograph could be used to produce images at one end, to convert them into radio waves of appropriate modulations, transmit those radio waves and receive them on another oscillograph that would reconvert them into images. In short, the glass end of one cathode-ray tube could act as a television camera, and the glass end of another as a television screen.

That, too, was easier to say than to do. Nevertheless, in 1926, a British inventor, John Logie Baird (1888-1946), managed to turn the trick. He used oscillographs that scanned an image by sending a beam of light across the image from one side to the other, first along the top, then a little farther down, then a little farther down still, until thirty lines had been scanned from top to bottom.

Since electron streams were used, it was done very rapidly and delicately. The whole scanning was completed in a tenth of a second, and then repeated in the next tenth

of a second, and so on.

Although at any one instant in time, there was only a single spot of light on the screen, of some particular brightness or other, the persistence of vision that I mentioned last month made it possible to see the entire screen as a pattern of light and dark, and, moreover, as a result of successive scannings, to see the image move.

Baird's picture was very small and it flickered badly, so that it was merely a laboratory curiosity, however. There was no chance of it having commercial possibilities.

The next step was taken by a Russian-American physicist, Vladimir Kosma Zworykin (1889-1982), who developed the first practical television camera in 1938. (His first patent in this direction was filed as early as 1923.) He called it an "iconoscope," from Greek words meaning "to see images."

In the iconoscope, the rear of the camera was coated with a large number of tiny cesium-silver droplets. Each emits electrons as the light beam scans it, and does so in proportion to the brightness of the light. If the light beam is reflected from some particular view, the pattern of light and dark in the reflection is mimicked by the pattern of electrons in greater and lesser quantity issuing from the droplets. This creates a varying electric current that can be reconverted into a light-and-dark pattern on a television screen many kilometers away.

After that it was a matter of refinement. In place of Baird's 30 lines, 10 times a second; there were perhaps 525 lines, 30 times a second. The stage was set for the commercial appearance of television, but World War II broke out and placed everything on hold. It was not till after the end of the war that television finally reached the general public in quantity.

By 1949, there were a million television sets in the United States, and I don't have to describe the growth since. It is frequently said that there are more television sets in the United States than there are bathtubs, and the disparity may be greater in other nations.

By the mid-1950s, color television was beginning to come in.

At the heart of the electronic devices that were sweeping the world were the various radio tubes that made them all practical. It seems rather ungrateful to point out that they were also weak spots in those devices.

Each radio tube had to be fairly large, since enough vacuum had to be enclosed for filament, grid, and various plates to be far enough apart so that electrons wouldn't jump the gap until encouraged to do so. This

meant that radio tubes were relatively expensive and bulky. They were also fragile and were short-lived, since the filaments, which had to be operated at high temperatures, gradually evaporated and broke and since the tiniest leak ruined the vacuum. In addition, there was always a time-consuming "warm-up" period since the tubes wouldn't work until the filament was hot enough to emit electrons properly. (Fragility was a particular characteristic of early television sets, and those of us who watched TV avidly in the 1950s remember well when the TV-repairman was virtually a live-in member of the family.)

Tubes were not the only devices that can act as rectifiers and amplifiers, however. Braun, who invented the oscilloscope, also showed that certain crystals would work as rectifiers. This was useful in early radios which were referred to as "crystal sets," and Braun shared the Nobel Prize with Marconi in 1909 as a result.

The crystals used in those early days were unreliable, and the proper spots on them had to be found. They were replaced by the far superior radio tubes when they came in.

But then, in 1948, the British-American physicist William Bradford Shockley (1910-1982) and his two American colleagues, Walter Houser Brattain (1902-1987) and John Bardeen (b. 1908), discovered a new kind of crystal that was named by a colleague, John Robinson Pierce (b. 1910), a "transistor." Because transistors did the work of a vacuum tube within the confines of a solid crystal and without requiring the use of a vacuum, they are called "solid-state devices."

By the mid-1950s, techniques had been worked out for developing reliable transistors and they began to be produced in quantity.

Because they were solid-state devices, they were rugged, did not break down, and did not develop leaks. They worked at room temperature so there was no warm-up period and they didn't burn out.

Most of all, they were small and cheap. Any device using radio tubes could be made much smaller ("miniaturization") by substituting transistors. (This is not quite true of television sets, for there, whatever else is made smaller, the television screen must remain large and must take time to warm up, too.)

As early as 1953, for instance, the old, bulky and embarrassing hearing aids were reduced in size by the use of transistors to the point where they could be fitted into the earpieces of spectacles and plugged unobtrusively into the ear canal.

As time went on, it was found

that solid-state devices could be made smaller and smaller; they became tiny "chips" and even tinier "microchips" on which electric circuits could be etched under a microscope.

Radios became small enough to fit into a vest pocket and played instantly when the switch was pushed. The same is true of computers, so that we now have vest-pocket computers that cost very little, consume virtually no energy, and are more rapid, complex and versatile than the huge energy-drunk computers that covered whole walls in the medieval 1950s.

Tiny, transistorized computers make it possible to produce machines that are capable of fulfilling complex repetitive tasks and have thus introduced "robots" to the world.

There could be no space age without transistors. The rockets and probes sent out into space could not be controlled and guided properly without advanced computers, and probes could do very little in the way of observing, recording, and sending back information were they not crammed full of tiny, complex transistorized devices.

In fact, after considering the airplane, the radio and the television set, one can only conclude that the greatest invention of the twentieth century was the transistor.

SCIENCE

ISAAC ASIMOV

ALL FOUR STANZAS

WHEN I was going to college, the United States was not yet out of the Great Depression, and I knew that I was not going to get a job after I graduated in 1939. The only thing I could do was to go on to graduate work, obtain some advanced degrees, and hope that the situation would have improved by the time I was through.

Now the problem was this: In what subject was I to get my Ph.D. (assuming I could be smart enough to get it and could find the money for tuition — for in those days there was very little in the way of grants to help out the impoverished)?

I was hung up between history and chemistry. I thought I could handle either one, but there was no question in my mind that I was more interested in history.

However, practical reasoning entered the field. I said to myself, "If I get my degree in history, then the chances are that if I get a job at all, I will get one in some small college, far away from my beloved city of New York, and that I will be working for a mere pittance with almost no possibility for advancement. On the other hand" (I continued saying to myself) "if I get my Ph.D. in chemistry, I may get a job with a large research firm for an ample salary with lots of room for advancement and with a chance, even, of winning a Nobel Prize, since I am so brilliant a person."

So I went for chemistry, and eventually, after a four-year delay because of World War II, I obtained my Ph.D. in chemistry in 1948.

The result? I went to work in 1949 as an instructor in biochemistry in a small medical school, far away from my beloved city of New York. I was working for a mere pittance and with no possibility of advancement. (Nor, I quickly realized, was there any chance at all that I would come closer than a light-year

or two to a Nobel Prize.)

As I frequently say: "There's a divinity that shapes our ends, rough-hew them how we will." (Hamlet said that also, and he may even have said it first.)

Chemistry was a big flop in another way, too. I really didn't like it and I was no good at it (except for being able to learn an encyclopedia of stuff about it, entirely because I can learn an encyclopedia of stuff about anything). What's more, as time went on, I grew less and less interested in it and, eventually, in 1958, I was fired simply because I was so uninterested in it that I refused to do any research. (I didn't mind teaching and writing books about it — I loved that.)

Of course, by that time I had another career, that of writing. In fact, my writing career began even while I was in college, when I was deciding what to do with myself — history or chemistry. Becoming a professional writer was a third option, but one that I didn't consider for even a split-second.

At the time I made my decision, I had sold a story or two, but never in my wildest imaginings could I possibly have believed I would ever do more than make occasional pin-money out of those stories.

And to tell you the truth, for a long time, I never did more than that. By the time I began my work at the medical school, I had written 68 stories and sold 60 of them in the course of eleven years. That was not too bad considering that the major part of my time had to be spent in my father's candy store, or at my graduate studies, or at a wartime job. However, in all that time, my total earnings for all eleven years amounted to $7700.

After I had been at work at the medical school for half a year, my first novel, *Pebble in the Sky*, was published, to be followed soon by others, and royalties started coming in; but even at the time I was fired in 1958, my literary earnings amounted to only $15,000 a year, enough to keep me going for a while in the absence of a job, but not enough to make me comfortable. (By that time, I had a wife and two children to support, too — and I was middle-aged.)

Now let's go back in time, to the point when I was first thinking about writing. Again, I had two choices. What I *really* wanted to write was historical fiction. I wanted to write a new kind of "Three Musketeers." The only trouble was that that would mean research. I would have to spend at least three years doing research in order that I might spend one year writing, and I didn't want to do that. I just *couldn't* do that. I wanted to *write*, not sit around taking notes.

The alternative was science fiction. That required research, too, for I had to know science. But I already knew science thoroughly, and besides I could make up science of the future — so I began to write science fiction, and as you all know I did pretty well.

But only pretty well. What was it that made me rich and famous? I'll tell you. As I continued to write science fiction, the urge to write historical fiction continued to gnaw away at me, and the impossibility of spending enormous time at research continued to keep me from doing anything about it — until a brilliant thought occurred to me, a thought that was at once encouraged by the great editor, John W. Campbell, Jr.

Why should I not write historical fiction of the future? I would deal with a social system, with politics, with economic crises, with everything that is to be found in history, except that it would all take place in the future and I would make it up. I wouldn't have to do any research.

Therefore, I began writing my *Foundation* novels, and my *Robot* novels, and, in due course, I became rich and famous.

Twice I had shoved history, my one great love, to one side, and despite that, it was history, in the end, that made me. I repeat, "There's a divinity that shapes our ends, rough-hew them how we will." (Is it possible Hamlet stole that from me?)

Once I got to the point where I was so well known that I was able to write what I wanted to write in full knowledge that it would be published, I switched to non-fiction, writing books not only on science but on history. I wrote nearly twenty books of history for young adults — on Egypt, Greece, Rome (two volumes), the Dark Ages, Canaan, Constantinople, the United States (four volumes), and so on. Even my science books and essays were strong on historical detail, as all of you know.

I had to stop my histories when Doubleday insisted that I return to science fiction novels, but not entirely.

For instance, I wrote a 450,000-word history of science, year by year, from the earliest times, and it was published by Harper's in October 1989, as *Asimov's Chronology of Science and Discovery*, and it was well-received, too. However, though Harper suggested that for each year I add a footnote as to what was happening in the world outside science at that time, I did it so enthusiastically that the book would have been more like 750,000 words long. Harper's couldn't manage that, and

they trimmed most of the straight history away.

Annoyed, I then proceeded to write another 450,000-word book, this time of straight history, period by period, country by country, and had more fun than you could possibly imagine. I did it without a contract, out of love alone, and showed it to Harper Collins (new name) only after it was all done. It will be published by them in 1991 under the title *Asimov's Chronology of the World.*

And, as you all know, I occasionally write straight history even in this column, which is ordinarily devoted to science essays, because the Noble Editor never interferes with my little quirks. And I will do so now.

I am not one of your professional patriots, you must understand. I am not a flag-waver (I don't even own a flag) and I eschew nationalism. I'm a globalist, who believes that human beings should not divide themselves into any divisions less than "human being." Let everyone be merely different facets of an overriding humanity.

However, even the best of us have our weaknesses, and I have one — I am crazy, absolutely nuts, about our national anthem. The words are difficult, the tune is almost impossible, but I sing it frequently when I'm taking my shower — *all four stanzas* — with as much power and emotion as I can possibly manage. And it shakes me up every time.

It bothers me no end, then, that hardly any American can sing the tune, hardly any American knows the words even to the first stanza, and hardly any American cares. They'll wave the flag assiduously, but they won't sing the song that celebrates the flag. And they don't know the absolutely thrilling story behind it. When they want to sing something they think of as patriotic, they sing Irving Berlin's "God Bless America," with words and tune as trite as you can imagine.

In fact, most national anthems are hymns, slow and stately and sleep-provoking. The only two anthems, beside our own, that I can think of as blood-stirring, are the French "Marseillaise" and the old Soviet "Internationale" (which they have replaced with something that is incredibly dull). But *our* national anthem takes first place, and easily.

I was once asked to entertain a luncheon club I belong to called "The Dutch Treat Club." I was given only a few hours notice, since it was well known I required no preparation. Taking my life in my hands, I announced I was going to sing all four stanzas of our national anthem. This was greeted with loud groans, and one member rose to close the

door to the kitchen, where the noise of dishes and cutlery was loud and distracting.

"Thanks, Herb," I said.

"That's all right," he said. "It was at the request of the kitchen staff."

I then explained the background of the anthem and sang all four stanzas, and let me tell you that those Dutch Treaters had never heard it before — or never listened, anyway. When I was done, I got a standing ovation and cheer upon cheer. It was not me, it was the anthem.

Then a couple of weeks ago, Roseanne Barr of television shrieked the anthem before the beginning of a baseball game and was booed. I was hurt. The anthem should not be sung as a publicity stunt, and the public should not boo, when they themselves know nothing about it.

On August 1, 1990, I was at the Rensselaerville Institute in upstate New York, conducting my 18th annual seminar. I seized the opportunity to tell them the story of the anthem and to sing all four stanzas. And *again* there was a wild ovation and prolonged applause. Again, it was the anthem and not me.

So now let me tell *you* the story of how it came to be written.

In 1812, the United States went to war with Great Britain over the matter of the freedom of the seas. We were in the right. For two years, we held the British off even though we were still a rather weak country and Great Britain was a strong one.

The reason we held them off was that Great Britain was in a life-and-death struggle with the French Emperor Napoleon and had little time or breath to fight another war across three thousand miles of ocean. In fact, just at the time that the United States declared war, Napoleon marched off to invade Russia; and if he won, as everyone expected him to, he would control all of Europe and Great Britain would find itself alone and isolated in opposition to the Emperor. It was no time for her to be involved in an American war, and if the United States had been more patient and if communications across the ocean had been faster, Great Britain would have given in to American demands in time to prevent what was really an unnecessary war.

American land forces did very poorly, the only competent military officer we had being Winfield Scott. At sea, we did well. American ships and American seamen proved better, ship by ship, then the British, to the world's surprise (and especially to Great Britain's). We also won a battle on Lake Erie in 1813, when the American commander, Oliver Hazard Perry, using ships he

had had built on the spot for the purpose sent the famous message, "We have met the enemy and they are ours."

However, the weight of the British navy beat down our ships eventually, and the United States was under a tightening blockade. New England, particularly, was hard-hit economically and it threatened secession.

Meanwhile, Napoleon was beaten in Russia and in 1814 was forced to abdicate. Great Britain could now turn its attention to the United States, and it organized a three-pronged attack on the country. The northern prong was to come down Lake Champlain toward New York to cut off disaffected New England. The southern prong was to go up the Mississippi to take New Orleans and to paralyze the west. The central prong, the most important, was to head for the mid-Atlantic and take Baltimore, the greatest port south of New York.

If Baltimore was taken, the nation, which still hugged the Atlantic coast for the most part, would be split in two. New England would certainly secede, and the United States would have to sue for peace, and it might well be a Draconian peace for Great Britain was very annoyed at the United States for distracting it in its fight against Napoleon. (The British asked the Duke of Wellington to lead the assault, but he refused.)

The north and south prongs might succeed or fail; they were not crucial (and in the end, each failed). It was the central prong that counted. On its success or failure rested the death or life of the United States.

The British reached the American coast and, on August 24, 1814, they took Washington. President James Madison and the rest of the government fled. The British then burned the public buildings including the Executive Mansion. It wasn't much of a fire and it didn't do much damage; nor was there any looting. Later on, the Executive Mansion was painted white to hide the scorch marks, and it has been known as "the White House" ever since.

Washington didn't count, though. It was a little shantytown of no importance except that it housed the government, so that it had symbolic value. The British ships then moved up Chesapeake Bay toward Baltimore, their real objective. On September 12, 1814, they arrived, and they found 13,000 men in Fort McHenry, whose guns controlled the harbor. If the British wished to take Baltimore they would have to silence those guns and take Fort McHenry.

On one of the British ships was

an aged physician who had been captured in Washington and who had been brought along, for some reason, as a prisoner of war. An American lawyer in Baltimore, Francis Scott Key, who was a friend of the physician, came to the ship to try to negotiate his release. The British captain was quite willing, but it was now the night of September 13-14, and the bombardment of Fort McHenry was about to start. They could not be released till the bombardment was over.

Key and his physician friend had to wait through the night. They saw the American flag flying over Fort McHenry as twilight deepened and night fell. Through the night, they heard the burstings of bombs and saw the red glare of rockets, and while that was going on, they knew that the Fort was still resisting and the American flag was still flying. But then, toward morning, the bombardment ceased and a dread silence fell.

There were two possibilities. Either Fort McHenry had surrendered and the British flag now flew above it, or the bombardment had been a failure and had been stopped and the American flag still flew over the Fort. If it was the former, the United States might well be through as a nation; if the latter, it would survive.

But which was it? As dawn began to brighten the eastern sky, Key stared out the porthole trying to see which flag was flying over the Fort. Bedridden and unable to look for himself, the physician asked over and over again, "Can you see the flag? Can you see the flag?"

After it was all over, Francis Key wrote a four-stanza poem telling the events of the night. It was published in newspapers on September 20 and it swept the nation. It was noted that the words fit an old drinking tune called "To Anacreon in Heaven," and it was sung to that (a difficult tune with an uncomfortably large range). Key called the poem "The Defense of Fort McHenry," but, for obvious reasons, it quickly became known as "The Star-Spangled Banner." Eventually, in 1931, Congress officially declared it to be the national anthem of the United States, and a flag flies over Francis Scott Key's grave, day and night, though ordinarily the flag is not allowed to fly at night.

Now that you know the story, here are the words to the first stanza, and how I wish I could sing it to you. I don't have the best voice in the world, but it is adequate, considering my age, and I sing it (believe me) with a wealth of emotion.

It is the old doctor speaking from his bed, and here is what he is asking Key:

Oh, say, can you see, by the dawn's early light,
What so proudly we hailed at the twilight's last gleaming?
Whose broad stripes and bright stars, through the perilous fight,
O'er the ramparts we watched, were so gallantly streaming!
And the rockets' red glare, the bombs bursting in air,
Gave proof through the night that our flag was still there.
O say, does that star-spangled banner yet wave
O'er the land of the free and the home of the brave?

"Ramparts," in case you don't know, are the walls or other elevations that surround a fort to help protect the personnel within.

This first stanza only asks the question. It is the second stanza that gives the answer, and it goes as follows:

On the shore, dimly seen through the mists of the deep,
Where the foe's haughty host in dread silence reposes,
What is that which the breeze, o'er the towering steep,
As it fitfully blows, now conceals, now discloses?
Now it catches the gleam of the morning's first beam,
In full glory reflected now shines on the stream:
'Tis the star spangled banner! O long may it wave
O'er the land of the free and the home of the brave.

"The towering steep" is, again, the ramparts. Obviously, the bombardment has failed, and Fort McHenry remains in American hands with the American flag still flying. The British fleet can do nothing now but sail away, their mission a failure, so the United States survives.

In the third stanza, Key allows himself to gloat over the American triumph and to shout abuse at the British enemy. It is not a very nice thing to do in cold blood, but Key, in the immediate aftermath of the bombardment was in no mood not to be cold-blooded.

However, the enemy are the British, and during World War II, when the British were our staunchest allies against a new and far more hideous enemy, it seemed that this third stanza was unnecessary, and it was removed from the anthem. However, I know it, and I am foolish enough to want to share the gloating, so here it is:

And where is that band who so vauntingly swore
That the havoc of war and the battle's confusion
A home and a country should leave us no more?
Their blood has wiped out their foul footsteps' pollution.
No refuge could save the hireling and slave
From the terror of flight, or the gloom of the grave:
And the star-spangled banner in triumph doth wave
O'er the land of the free and the home of the brave.

That leaves the fourth stanza, which is a pious hope for the future and which has the atmosphere of a hymn at last. It should, to my way of thinking, be sung more slowly than the other three and with even deeper feeling. Here it is:

Oh! thus be it ever, when freemen shall stand
Between their loved homes and the war's desolation!
Blest with victory and peace, may the heaven-rescued land
Praise the Power that hath made and preserved us a nation.
Then conquer we must, while our cause it is just,
And this be our motto: "In God is our trust."
And the star-spangled banner forever shall wave
O'er the land of the free and the home of the brave!

The fourth stanza as I've given it here is the way I sing it. I have taken the liberty of making two small changes from the way the song appears in the reference books and, presumably then, the way that Key wrote it.

In the fourth line, Key wrote, "Then conquer we must, for our cause it is just." Key was writing about the War of 1812, when, as I believe, our cause *was* just, but I am not ready to assume that our cause is always just. The United States is as capable of fighting an unjust war as any other nation is, although I earnestly hope it doesn't do so often.

The Mexican War was an unjust war, a naked war of aggression, a war to fasten slavery on Texas after Mexico had freed the slaves there and to seize territory to which we had no real right. But we won every battle just the same, established slavery in Texas, and took the entire southwest. The Spanish-

American War was not particularly just, either.

The southern states of the Union, after seceding to form the Confederate States of America, stood between their loved homes and the war's desolation and did so with magnificient bravery for four years, but lost in the end and (in my opinion) rightly so, for they fought for slavery.

The Vietnam War (again in my opinion) was an unjust war, for we travelled 6000 miles to take part in a civil war that was not really our business and held no threat whatever to our vital interests. The old "domino theory" was just a fraud used to justify what could not really be justified. And we lost, as we should have.

But now (as I write) Iraq has invaded Kuwait and taken it over. This was unjustified aggression and *does* affect American vital interests, for Iraq intends to control the world's oil supply to its own advantage. If we take measured action, I will consider our cause to be just.

Let me go on. The other change I have made is in the next to the last line where Key apparently repeated that the star-spangled banner "in triumph shall wave." I don't think that the third and forth stanzas should end equally. I want the end of each stanza to represent a new and higher climax, so I replaced the last "in triumph" with "forever."

When I sing "The Star-Spangled Banner," I don't try for vocal tricks, which I don't have the voice or the technique for, never having had even a day's training in voice. I try only to enunciate carefully so that the audience hears every word without fail.

Nevertheless, when I sing that last stanza, I do try one little trick. I linger over the "forever" and make my voice louder and even more emotional and I can feel the audience respond to that.

I sang all four stanzas in public only twice, but each time it was a memorable experience for me, and, I believe, for the audience as well. Now I do it for a third time, in print only, and without the additional dimension of my voice (such as it is).

I can only hope that you get a bit of what the national anthem means to me and that you will look at it with new eyes, and listen to it, the next time you have a chance, with new ears.

And don't let them take it away and substitute "God Bless America," for goodness sake.

SCIENCE

ISAAC ASIMOV

SKIMMING THE NEAREST

I RECEIVED A letter about a week ago, as I write this, from a reader who informed me, much more in sorrow than in anger, that I was wrecking his life. Apparently, as a result of reading my books and essays on science, he was inspired to do the same himself. On reflection, however, he decided that he couldn't because I had covered everything so thoroughly that I had left no room for him.

Naturally, I replied at once, because I am sensitive to any possibility that I make life difficult for others. I said something like the following:

"Why should it bother you what I write? You go ahead and write your own things in your own way, and there are bound to be people who would prefer your versions to mine. After all, do you suppose that when I write my books or essays I worry for one moment that someone else has already covered the subject? Never! Even if they have, I have my own voice and my own pleasure in using it, and I expect you have yours."

I hope he takes my advice.

As a matter of fact, I have no hesitation in overlapping myself when necessary. This is my 390th F & SF essay, and if you went through every one of them carefully, you'd find a good deal of overlapping here and there, although I think there are no actual duplications.

For instance, it occurred to me to write an essay on the planet Mercury, and I decided I would call it "The Seventh Planet" because, in my opinion, it was the seventh planet (the word being used in the old Greek sense) to have been discovered. That having been decided I bent myself to the task of remembering what I had already written on the subject in this essay-series.

Unfortunately, although I keep meticulous records, I have to remember the title of a particular

essay before I can use my records to locate it, and I am so addicted to "cutesy" titles that I can't always tell from the title what I was talking about. Moreover, knowing the subject won't necessarily tell me what title I made use of.

In this case, however, it was easy. After a little thought, it came to me that I had indeed written an article on Mercury and had called it (what else?) "The Seventh Planet." It appeared in the March 1968 F & SF. That is nearly a quarter of a century ago so you'll forgive me, I know, that it took me a little thought to remember it. What's more, in the April 1968 issue, I wrote a continuation piece entitled "The Dance of the Sun." (You will find both essays in my collection *The Solar System and Back*, published by Doubleday in 1970.)

Those two essays dealt with Mercury and Venus, but primarily with their orbits, the manner in which they circled the Sun, the apparent motions of the Sun in their skies, and so on.

I can't prevent a little overlap, if I am to write a sensible essay on Mercury now, but let me talk a little about Mercury as a physical body, something I didn't do in those early essays because at the time, we didn't know as much about it as we do now. Naturally, I'll use a different title for this one, which is why I am calling it "Skimming the Nearest."

First, let's set up our boundary conditions. There are uncounted numbers of independent objects in the Solar system, but let's leave out the small and inconsiderable ones: the dust particles, the meteoroids, the asteroids, the comets. Let's leave out the small and inconsiderable satellites. Let's even leave out Pluto, which is more nearly a medium-sized satellite that has somehow gotten loose than a respectable planet.

That will give us fifteen "worlds," that is, sizable objects. They are eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune; and seven satellites: Moon, Io, Europa, Ganymede, Callisto, Titan and Triton.

Five of these worlds make up the "inner Solar system": Mercury, Venus, Earth, Moon and Mars. The other ten are the major components of the "outer Solar system."

Mercury is the smallest of the eight planets. Its diameter is 4878 kilometers (3031 miles). Compare this with the diameter of the other three planets of the inner Solar system: Earth, 12,756 kilometers (7926 miles); Venus, 12,104 kilometers (7521 miles); and Mars, 6794 kilometers (4222 miles).

Mercury is, however, larger than the Moon, the diameter of which is

3476 kilometers (2160 miles).

There are, however, two satellites that are larger than Mercury. These are Ganymede, Jupiter's largest satellite, which has the diameter of 5262 kilometers (3270 miles); and Titan, Saturn's largest satellite, with a diameter of 5150 kilometers (3200 miles). Jupiter's second largest satellite, Callisto, has a diameter almost equal to that of Mercury, 4800 kilometers (2982 miles).

From our lordly position on Earth, we can look down on these smaller worlds as comparatively insignificant, but we get a truer picture if we consider the surface areas. The Moon, which is the smallest of the eight worlds we have just considered, has a surface area of 38 million square kilometers (14.7 million square miles), which is about as large as Africa and Europe put together. That's not bad for a "small" world — plenty of room to get lost in.

Mercury and Callisto have surface areas that are just about twice as great: 75 million square kilometers (29 million square miles). That is as large as Africa and Asia put together. Ganymede and Titan have surface areas of 85 million square kilometers (33 million square miles), as large as Africa, Asia, and Europe put together.

As for Mars, that has a surface area of 145 million square miles, just about as large as the entire land area of Earth, while Venus has a surface area nearly that of Earth (land and water).

These are all respectable worlds, you see.

In a way, a truer measure of the size of a world is its mass. After all, you can have a world made of balsa wood, so to speak, and another made of platinum. The former may bulk larger in volume, but the latter will be more massive, and it is mass that governs the gravitational field.

The Moon, for instance, has a mass of 73.5 trillion trillion grams, and let's set that equal to one.

In that case, here are the masses for the 8 worlds we are considering:

Moon	1.00
Callisto	1.47
Titan	1.83
Ganymede	2.02
Mercury	4.47
Mars	8.70
Venus	66.7
Earth	81.3

You can notice two things from this list. First, the Earth has just about half the mass of all the worlds in the inner Solar system. Second, Mercury may still be the smallest of the eight planets, but it is distinctly more massive than any of the satellites. It is 2¼ times as massive as Ganymede, the largest and most

massive of the satellites.

This reflects itself in the surface gravity, which depends on the mass of the world (the larger the mass, the more intense the surface gravity) and the size of the world (the smaller the radius, the more intense the surface gravity).

Here are the surface gravities for our eight worlds, if Earth's surface gravity is set equal to one:

Moon	0.16
Callisto	0.12
Titan	0.13
Ganymede	0.14
Mercury	0.38
Mars	0.38
Venus	0.95
Earth	1.00

Notice that the outer-Solar system satellites, Callisto, Titan, and Ganymede, are fluffy worlds built up largely of icy materials so that their extra size carries the surface away from the center without building up very much additional mass. The surface gravity of all four satellites is about the same, therefore, with the Moon, the smallest of the four but the most compact, having rather the edge.

Again, Mercury, a compact world, has the same surface gravity as Mars, a distinctly larger, but less compact world. A 70-kilogram person (154 pounds) would weigh 11.2 kilograms (24.6 pounds) on the Moon and 8.4 kilograms (18.5 pounds) on Callisto, but 26.6 kilograms (58.5 pounds) on either Mercury or Mars.

Another interesting extreme about Mercury is that it is the closest of all the worlds to the Sun. Its orbit is distinctly elliptical, more so than any of the other seven planets and more so than any of the seven satellites circling their planets.

The measure of the ellipticity is the "eccentricity," which can vary from zero for a perfect circle to one for an infinitely long ellipse (i.e. a "parabola.") For instance, the eccentricity of Earth's orbit about the Sun is 0.0167, quite close to zero. Venus's orbit does even better with an eccentricity of 0.0068, while Mars's orbit has one of 0.093. The Moon's orbit around the Earth has an eccentricity of 0.055.

Now compare this with the eccentricity of Mercury's orbit, which is 0.206. This means that the distance of Mercury from the Sun varies more greatly (proportionately to the size of its orbit) than does that of any other world; or any of the four worlds we have been discussing that circle planets.)

At one point in its orbit, Mercury can be as close as 45.9 million kilometers (28.5 million miles) from the Sun. That is its "perihelion," and it is only 3/10 the distance of

the Earth from the Sun. At the opposite end of its orbit, the "aphelion," Mercury is at 69.7 kilometers (43.3 million miles) from the Sun. The average distance is usually taken as the "semi-major axis"; that is the perihelion plus the aphelion, divided by two. It is 57.8 kilometers (35.9 million miles).

There are objects that approach the Sun more closely at perihelion than Mercury does. There is the asteroid Icarus, for one, and the recently discovered Phaethon. There are also a number of comets that skim by the Sun at very close distances — some so close that they actually drop into the Sun. In every single case, however, these asteroids and comets are far removed (even *very* far removed) from the Sun at aphelion.

Of all the objects that circle the Sun, Mercury has (as far as we know) the smallest semi-major axis. This means that its period of revolution about the Sun is smaller than any other object, for Mercury's period of revolution is only 88 days long.

Being so close to the Sun, it races along its orbit more quickly than does any other planet. Earth's average orbital speed is 29.8 kilometers per second (18.5 miles per second). Mercury at aphelion moves along at 38.7 kilometers per second (24.0 miles per second) and at perihelion at 56.6 kilometers per second (35.2 miles per second). Those objects which approach the Sun more closely than Mercury move even faster at perihelion, but no known object has a faster *average* orbital speed than Mercury has.

During the 19th Century, it was found that Mercury's perihelion progressed around its orbit slowly. It was supposed to do so because of various gravitational pulls upon Mercury. However, in 1845, the French astronomer Urbain J.J. Leverrier (1811-1877) carefully calculated all the pulls on Mercury and found that the point of perihelion advanced at a very small rate in excess of that predicted by gravitation. The excess amounted to 43 arc seconds per century, which meant that the perihelion would make a complete circle of the orbit, for unexplained reasons, in just over 3 million years.

This means, if I may trust my back-of-the-envelope calculations that every time Mercury circles the Sun, the perihelion advances by 209 kilometers in defiance of the law of gravity. This was not explained until 1916 when Albert Einstein (1879-1955) worked out his Theory of General Relativity. Einstein's modification of Newton's equations neatly explained the advance of Mercury's perihelion.

Other planets also had a relativistic perihelion advance, but the

farther they were from the Sun, the smaller it was. What's more, the more nearly circular the orbit, the more difficult it was to pinpoint the perihelion accurately. The combination of Mercury's closeness to the Sun and its high orbital eccentricity made it ideal in this respect, and it offered the first corroboration of Einstein's theory.

Astronomical bodies consist of four classes of substance, in order of increasing density and decreasing quantity: 1) gases (chiefly hydrogen and helium); 2) ices (chiefly water, ammonia, methane, and carbon dioxide); 3) rocks (chiefly magnesium and aluminum silicates); and 4) metals (chiefly nickel-iron). They arrange themselves in strata, the gases on top, the ices below, the rocks farther below and the metals at the center.

Very large bodies possess all four but are overwhelmingly gaseous in nature. This is true, within our Solar system, of the Sun and of the four gas giants: Jupiter, Saturn, Uranus and Neptune.

Smaller bodies can't retain the gases and may be mostly icy in nature, as, for example, Triton, Titan, Ganymede, and Callisto. If warm enough, such bodies lose most of their ices and are chiefly rocky.

Europa, for instance, is a rocky object with a coating of ice (and possibly liquid water). Io retains ices in the form of sulfur compounds. Mars and Venus retain carbon dioxide, while Earth retains an atmosphere and an ocean.

The ice content of the worlds in the inner Solar system is, however, minor and can be ignored. If they are, then Mars, Earth, Venus, Mercury and the Moon are essentially rocky worlds with metallic cores.

The densities of these five worlds are:

Moon	3.3 grams per cubic centimeter
Mars	3.9 grams per cubic centimeter
Venus	5.24 grams per cubic centimeter
Mercury ...	5.43 grams per cubic centimeter
Earth	5.52 grams per cubic centimeter

The comparatively low density of the Moon and of Mars indicates that their structure is almost entirely rocky in nature. A metallic core, while it must surely exist, must also be comparatively small.

Venus, Mercury and Earth are the only worlds in the Solar system that have *large* metallic cores, as is evidenced by their comparatively high density.

Earth has the highest density of all, but that is deceiving. Some of the density is the result of the high compression of the innermost regions of the planet. Since Earth is distinctly larger than the other

worlds of the inner Solar system, its compression effect is great. If there were no such compression, the Earth would have a density of only 4.4 grams per cubic centimeter. Mercury, a smaller planet, has much less compression in its interior, and if that is imagined to be removed, Mercury's density would shrink only slightly to 5.3 grams per cubic centimeter.

This means that Mercury must have a larger metallic core in relationship to its total size than Earth has.

Thus Earth's metallic core forms a smaller sphere within the larger rocky sphere of the planet. Earth's metallic core is 5360 kilometers (3320 miles) in diameter. This is fully 42 percent of the Earth's total diameter, but volume varies as the cube of the diameters, so Earth's iron core makes up just about 1/14 the volume of the Earth. The other 13/14 is rock.

Mercury, on the other hand, is estimated to have an iron core that is only 3660 kilometers (2275 miles) in diameter, so it is only 1/3 the volume of Earth's iron core. However, Mercury is far the smaller planet so its metal core, though small in comparison to Earth's, makes up 2/5 the volume of the planet.

No world in the Solar system is nearly as metallic as Mercury is, and one has to ask why.

Mercury formed in the very hottest part of the dust cloud that gave birth to the planets, and perhaps conditions were such as to render that part of the cloud comparatively rock-poor and iron-rich.

Another possible explanation, and perhaps a more likely one, is that Mercury, in its early history, was struck by another sizeable body (as we now think Earth was, in a collision that ended in the formation of the Moon). It may be that much of Mercury's rocky layers were smashed away but that the proximity of the Sun prevented the debris from coalescing into a satellite. Instead, the debris may have been driven away by the Sun's powerful primordial Solar wind. Mercury would thus be left with: a) no satellite, b) an unusually small overall size, and c) an impoverished rocky outer layer.

It would, however, be useful if Mercury could be studied in detail. It might give us hints as to the history of the early Solar system that we could not easily obtain in other ways.

Actually, Mercury was examined closely only once.

On November 3, 1973, "Mariner X" was launched. It passed by the Moon and then, on February 5, 1974, it passed by Venus at just

5800 kilometers (3600 miles) above the cloud layer of that planet and sent back useful data.

It then headed for Mercury, and on March 19, 1974, it passed within 700 kilometers (435 miles) of its surface.

It moved into an orbit about the Sun in such a way as to make one circuit in 176 days, or just twice Mercury's year. This brought it back to Mercury in the same spot as before, because each time the probe made one circuit of the Sun, Mercury was making two. Mariner X passed Mercury a second time on September 21, 1974, and then a third time on March 16, 1975. On the third pass, it skimmed within 327 kilometers (203 miles) of Mercury's surface. (This is why I am calling this essay "Skimming the Nearest.")

After the third pass, Mariner X had consumed the gas that kept it in a stable position, and it was thereafter useless for further study of the planet.

Mariner X confirmed Mercury's rotation rate and temperature and showed that it had no satellite and no significant atmosphere. It determined its diameter, mass, and density.

The photographs it took of Mercury showed a landscape that looked very much like that of the Moon. There were craters everywhere with the largest one photographed about 200 kilometers (125 miles) in diameter.

On the whole, Mercury had fewer craters than the Moon per unit area, particularly larger craters. This may be because Mercury's strong gravitational field prevented meteor collisions from making such large splashes.

The Moon, especially the side that faces us, has large "maria." These are relatively flat basins that early in the Moon's history must have formed as lava flows. Mercury is not as rich in basins as the Moon is. The largest one sighted is about 1400 kilometers (870 miles) across, and is called "Caloris" ("Heat"), because it is just about at the spot on Mercury that is under the Sun at zenith, when Mercury is at perihelion and the Sun's heat is the greatest.

Mercury possesses long scarps, or cliffs, that are several hundred kilometers long and about 2.5 kilometers (1.5 miles) high. These cliffs may be cracks that appeared in the outermost crust as the interior cooled and shrank.

In addition, Mercury reflects more Sunlight than the Moon does, and its color is not quite the same. That means its chemical composition is probably significantly different from that of the Moon.

Unfortunately, each time that

Mariner X returned to Mercury it viewed pretty much the same portion of Mercury's surface. The result was that photographs were only taken of 3/8 of Mercury's entire surface. The remaining 5/8 may be much like we've seen, but we can never be sure. The Solar system has been too full of surprises in the last thirty years for astronomers to take anything for granted.

There are, however, no plans at the moment for a return to Mercury, so astronomers will have to endure the inability to satisfy their curiosity in this respect.

The most puzzling discovery that Mariner X made concerning Mercury was the presence of the planet's small magnetic field.

Magnetic fields are common in connection with astronomical bodies, but there are two requirements. First, there must be a core that is liquid and can carry an electric current. Second, there must be some force that sets that liquid to swirling, for a rotating electric current will set up a persistent magnetic field.

The Sun, for instance, has a core in which matter has broken down or degenerated to free electrons and free nuclei, which are each electrically charged. The Sun's rotation swirls the core material and sets up a magnetic field that produces the Sunspots, somehow.

The gas giants have cores that contain liquid metallic hydrogen, and their rapid rotations set them to swirling and produce intense magnetic fields. This is particularly true in the case of Jupiter, which is the largest planet, has the hottest core, and the most rapid rotation.

Earth has a magnetic field because it has a liquid iron core that is set swirling by the planet's rotation.

As for the remaining worlds of the inner Solar system, the Moon does *not* have a magnetic field because it has no liquid iron core to speak of, and it rotates so slowly that no swirls would be set up in such a core even if it possessed one. Mars rotates fast enough to set up swirls, but apparently it has very little in the way of a metallic core; and it is too small to keep it liquid, so it has no magnetic field. Finally, Venus is certainly large enough to have a liquid metallic core, but it rotates on its axis with such excessive slowness that it sets up no swirls and has no magnetic field.

Why is it, then, that Mercury has a magnetic field, only a small one to be sure, but it's there.

Of course, Mercury has a liquid metallic core, larger in proportion to the planet as a whole than any other planet has. Nevertheless, Mercury is so small that it is hard to see how that core can be heated

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sufficiently to liquefy it, unless it is not pure metal.

There are suggestions that sulfur is present, too, forming metallic sulfides that melt at temperatures lower than the metals themselves. If as much as 7 precent of the metallic core is sulfur, it should remain liquid.

But then, what would make that iron core swirl? Mercury's rate of rotation is very slow, slower than that of our Moon, and much slower than that of Mars. Granted that the Moon has no metal core to speak of, Mars at least must have one, albeit a smaller one than Mercury; and if Mercury can keep its core liquid why cannot the distinctly larger Mars do the same for its core? And if Mercury's slow rate of rotation is nevertheless fast enough to set up some swirling, should not Mars's considerably faster rotation rate do the same? Yet Mars does not have a magnetic field and Mercury does have at least a small one.

It's rather a puzzle.

SCIENCE

ISAAC ASIMOV

THIS PITILESS STORM

I CAN SOMETIMES be talked into doing something I don't really want to do, if it is placed half a year to a year in the future. After all (I say to myself) the world may well come to an end by that time, and I won't have to do it, so why not be agreeable?

And then, of course, the world *doesn't* come to an end, and I am stuck with my promise.

Many months ago, I carelessly agreed to get onto a sailboat and cruise New York Harbor for three hours. Having made the promise, I of course forgot all about it until the day before the event, when my dear wife, Janet, who knows me, said, "I suppose you've forgotten we're going on the sailboat tomorrow."

I answered, as expected, "What sailboat?" She told me, and I groaned piteously, but we had to go.

As it turned out, the weather was perfect, the sky was clear, the temperature was delightful, there was the brightest full Moon I have ever seen, and the skyline of the land areas about the harbor (especially Manhattan, of course) were breathtaking in their beauty.

But all that is beside the point. The point is that it was a Tuesday, and every Tuesday I preside over the luncheon meetings of the Dutch Treat Club and have a great old time.

This time, however, I received specific instructions. "You cut it short, Isaac," said Janet. "We have to leave at 4:30, and I want you home in time to take a nap before we go."

I did as I was told and, as soon as I finished eating, I rose to leave, skipping the post-meal talk, which is the best part. Naturally, I was not my usual sunny self, and my expression was so disagreeable and lowering, I frightened the others.

They called out, "What's the matter, Isaac? Is something wrong?"

"Yes," I replied, grinding my

teeth. "I've got to go out on a sailboat for a three-hour cruise of New York Harbor, and I won't get a chance to sit home and work."

I fully expected to have everyone burst into tears of sympathy, but they did *not*. Instead, they burst into laughter, one and all, and many were the jocose remarks I had to listen to about what a hard life I led, being forced to cruise instead of work.

But it *is* a hard life when that happens, and no matter how beautiful the cruise was, I mourned the loss of an evening's work.

However, I'm working right now, and *this* is what I consider fun, relaxation and pleasure. So let's get on with it —

The most dramatic storm in all literature, to my way of thinking, is the storm into which King Lear was thrust by his ungrateful daughters in Act III of that play. (The play, incidentally, is not about ingratitude or injustice or anything like that. What the play is really about is the regeneration of a man through suffering.)

Lear had spent his entire adult life as a tyrannical monarch, sopping up admiration and striking out impulsively in all directions. He is shown at his worst at the beginning, when he asks for sycophantic praise, then bespatters his one worthy daughter, Cordelia, with cursings because she wouldn't oblige him. Believe me, he deserved what he got.

Then, in the storm, when he was at his lowest pitch, a miraculous change comes over him, which Shakespeare, being a miraculous writer, makes us believe. Alone on the stage, this eighty-year old man, who had never before in his life given a thought to anyone but himself, is driven by adversity to think of others. He says:

Poor naked wretches, whereso'er you are,
That bide the pelting of this pitiless storm,
How shall your houseless heads and unfed sides,
Your loop'd and windowed raggedness, defend you
From seasons such as these! I have ta'en
Too little care of this! Take physic, pomp.
Expose thyself to feel what wretches feel,
That thou mayst shake the superflux to them
And show the heavens more just.

With that, Lear begins to change, and by the end of the play, he is a new man who has learned how to live. *That* gives the play its happy ending despite the fact that Lear and Cordelia both die pitifully.

I think of the terrifying scene of "this pitiless storm" frequently, but, being who I am, I can't help but also think that anything the Earth can produce, any storm it can whomp

out, is but a baby's puff to storms on other worlds. Consider Jupiter, for instance, which is the largest of the planets of our Solar system, with 11.2 times the diameter of Earth and 317.8 times its mass.

Naturally, it was not till modern times that there was the slightest indication that Jupiter was so large. It was seen as only a dot of light in the sky. To be sure (if we omit the Sun and the Moon) only Venus was brighter than Jupiter, and Venus shone for only a few hours after Sunset or before Sunrise. Jupiter, nearly as bright, could shine in the sky all night, and it seemed natural, then, to name it for the predominant god, which was Jupiter to the Romans (and to us).

It was not until January 1610 that anyone saw Jupiter as more than a dot of light. In that month, Galileo looked at Jupiter with the telescope he had built, on hearing a rumor that something of the sort had been invented in the Netherlands.

He found that Jupiter was expanded into a tiny circle of light by the telescope, so that one could think of it to be a world. He also found four lesser bodies (which we now call "satellites") that circled Jupiter, showing for the first time that something in the heavens circled a body other than the Earth. This was an important step toward establishing the heliocentric theory of Copernicus, to the effect that the Sun, not the Earth, was the center of the planetary system.

Galileo's telescope was too small and primitive to show him any markings on Jupiter. So were the telescopes that succeeded him. Not only were they small and inefficient but they made use of lenses that refracted different colors differently so that no matter how carefully they were focussed they exhibited "chromatic aberration" in which everything had rings of color about it that confused the details.

Even so, fugitive glimpses were caught of markings on Jupiter's surface. In the 1660s, several observers reported having sighted darkish bands stretching across Jupiter. Thus, the English scientist Robert Hooke (1635-1703) reported in 1664 that he had seen them. The Italian-French astronomer Giovanni Domenico Cassini (1625-1712) reported them in 1665. Though Cassini was behind Hooke in this, he did something with his observation. For one thing, he suggested that the markings were cloud formations, which was correct. For another, he followed the markings as they made their way about the planet so that he was the first to measure Jupiter's speed of rotation.

It was 9 hours and 56 minutes, which was amazingly short, since

the much smaller Earth takes 24 hours to rotate about its axis. It was this very rapid rotation of Jupiter that explained why its outline was distinctly elliptical. The existence of a large centrifugal effect gave it an enormous equatorial bulge, much larger than Earth's puny one. (Saturn, though rotating somewhat more slowly than Jupiter, is made up of lighter materials and has a still larger equatorial bulge — the largest in the Solar system.)

Cassini also found that Jupiter rotated most rapidly at the equator (at least, it did so at the point where the bulge was at its peak, and everyone rightly assumed this to be the equator). Farther to the north and south, the rotation period was only 9 hours and 50 minutes. This was not surprising, since it could be assumed that all we saw of Jupiter was the top of the cloud layer. Naturally, the clouds might not necessarily rotate all in one piece.

Jupiter's rotation rate was determined more accurately by later astronomers, but the corrections were not greater than a few seconds.

In 1842, the German astronomer Friedrich Wilhelm Bessel (1784-1846) pointed out that it was possible to make use of Newton's law of gravitation to determine the mass of Jupiter by noting the distance of its satellites and their periods of revolution about the planet.

He was the first to make it clear that Jupiter was over three hundred times as massive as Earth. From its volume, however, it should have been more massive still. In point of fact, it had only a quarter the mass that the Earth would have had if the Earth were Jupiter's size (and if you neglected the additional compression produced by the gravity of this enlarged Earth).

This meant that Jupiter was made up of materials that were on the whole only about one-quarter as dense as those that made up the Earth. That made it seem logical to suppose it consisted largely, if not entirely, of gaseous material.

In fact, it seemed that Jupiter was more like the Sun than like the Earth. It had about the same density as the Sun had, so perhaps it was made of Sun-material rather than of Earth-material. (As a matter of fact, this turned out to be right.)

Then, too, perhaps Jupiter was a tiny Sun. It might be hot — not nearly as hot as the Sun, to be sure, but still hot enough to be faintly luminous on its own. (From Earth's position between the Sun and Jupiter, we only see the Sunlit half of the planet, never the night side — at least not till the age of planetary probes arrived — so that we could not see whether Jupiter's dark side was faintly luminous or not.

At least two astronomers in the

1870s strongly suggested that Jupiter was a tiny Sun and had its own luminosity. These were the German astronomer Hermann Karl Vogel (1841-1907) and the American astronomer Henry Draper (1837-1882).

This thought caught on among the more romantic followers of popular astronomy, and when I first started reading science fiction some sixty years ago, the hypothesis of a hot Jupiter (and Saturn, Uranus and Neptune as well) was quite prominent. For one thing it made the satellites of the gas giants more nearly habitable, and I believe I had the Jovian satellite Callisto warmed by a hot Jupiter in my early story, "The Callistan Menace."

It's not true, however. Jupiter is fearfully hot in its interior (as, to a lesser extent, is the Earth), but its surface is very cold and it has no luminosity of its own at all.

Contributing to the notion of a hot Jupiter was the most famous of all its markings, something that is now called "the Great Red Spot."

The first person who *may* have seen the Spot was Hooke in 1664, when he first reported markings on Jupiter. Cassini drew the Spot in 1672 and again in 1691.

There is some doubt about these 17th Century reports, for Jupiter's orb was not seen clearly with those early telescopes, and the descriptions were not quite like those that would be put forth now. It was not till the 1850s that telescopes were developed that were good enough to be relied on for studying Jupiter's surface markings.

The Spot was first seen clearly, and in detail, in 1878, by a German astronomer, Ernst Wilhelm Leberecht Tempel (1821-1889), who announced his discovery in 1879.

Tempel saw the Spot as a distinct brick-red in color. After a while it faded, sometimes to a pinkish-gray that is hardly noticeable. However, once seen it was never lost and could always be made out even when it was not very clearly marked off from the rest of Jupiter's surface. To Tempel it became the Great Red Spot, and it certainly has an unbroken history of a century and a quarter and, in all likelihood, one that is much longer than that.

The first thing to note about the Spot is its size. It is elliptical in shape, considerably longer from east-to-west than from north-to-south. Its long diameter is about 26,000 kilometers (16,000 miles), just twice the diameter of the Earth. Its short diameter is 14,000 kilometers (8700 miles) or just a little over the diameter of the Earth.

Its area is about 285 million square kilometers (110 million square miles). This means that it

occupies a little less than half a percent of the total surface area of Jupiter, but on an Earthly scale it would be much more impressive. The Great Red Spot is a little bigger in area than the Pacific Ocean.*

At first, it seemed that the Great Red Spot had suddenly appeared in 1878, for how could it have been missed if it existed before, considering its startling reddish color. When, after a few years, it faded considerably, astronomers thought it might be a temporary phenomenon. It might be a lava flow, perhaps, something that was red hot to begin with and was cooling down somewhat. Or perhaps it was the mark where a rather large asteroid had struck the planet, or even more dramatic, where a new satellite was being born. The general impression, though, was that if it was a temporary phenomenon it was the sort of thing that ought to develop briefly, now and then, on a hot planet.

It quickly turned out, however, that the Spot had been seen in earlier times, perhaps even as early as Hooke's report in 1664. Then, too, while the color might fade, it would also brighten at times, and it could always be clearly made out whenever good telescopes were pointed at Jupiter.

It is a long-lived phenomenon then, and the feeling arose that it might be some kind of enormous and, at least, semi-permanent storm. This was confirmed once the Voyager probes studied Jupiter at close-range in 1979, just one century after Tempel's report of the Spot's existence.

Very likely the Spot is an upper atmospheric phenomenon and does not reach down into the heated lower layers of the atmosphere very far. There is a solid core to Jupiter, for the central layers seem to be made up of metallic hydrogen, and at the very center there may even be a relatively small glove of rock and metal. Such solid portions of the planet are far too deep to affect the Spot, however.

In analyzing the behavior of the Spot, then, we have to deal with the atmospheric circulation of Jupiter only. For instance, why is the Spot so long-lived? On Earth, similar cyclonic storms eventually move over land and lose energy, but on Jupiter, there is no land, and energy may be supplied it on a permanent basis.

Because of the rapid rotation of Jupiter, the predominant winds in the "temperate zones" are westerlies that seem to move at a rate of 650

**The calculations in this paragraph were done in my head, and I haven't bothered to check them. This means I'm giving the readers a chance to check it themselves and correct me if I'm wrong. They always seem to enjoy a chance to do that.*

kilometers per hour (400 miles per hour), whipping the cloud formations into bands that run parallel to the equator.

These winds cannot be really steady, however. We know, from our studies of Earth's atmosphere that air movements tend to be chaotic and, therefore, unpredictable in fine detail. Jupiter's atmospheric circulation may be less complex than Earth's, since the temperature differences north and south are not as great as on Earth and because there is no land surface to complicate matters.

On the other hand, the greater speed and density of Jupiter's atmosphere makes for much more turbulence. It is not surprising, then, that changes in wind velocity may serve to move the Spot forward ahead of the general rotation at some times, and allow it to lag behind the general rotation at other times. The nature of the winds can also lengthen or shorten the long diameter of the Spot.

The strong westerly winds, however, keep the Spot firmly in place in its latitude. The Spot may drift east and west, but it never drifts north and south. Nor does its short diameter vary much.

One thing that is bothersome about the Spot, though, is the fact that it is asymmetrically placed on Jupiter. I suppose that in order to set up a vast storm, you need dense, rapid winds, and a strong Coriolis effect (the latter imparts a turning motion to the air, for reasons I'll take up in another essay someday, perhaps). The winds, I think, would be most rapid at the equator, but there is no Coriolis effect there. As one moves north or south of the equator, the winds slow down, but the Coriolis effect becomes larger, and at 20 South Latitude, it may be that the combination is ideal for producing a large storm.

But, then, there seems no reason for supposing that the wind systems are not symmetrical north and south of the equator. And in that case, why is there not a second Great Red Spot at 20 North Latitude? There just isn't and I don't think anyone knows why there isn't.

A second problem is the matter of color. Jupiter has surface colors of white, yellow, orange, brown, and reddish — but why?

The atmosphere is almost entirely hydrogen and helium, which are quite colorless. To be sure, there are also other components of Jupiter's atmosphere that exist in much smaller quantities — water, ammonia, methane, ethane, hydrogen sulfide and so on. It doesn't take much of some component to absorb part of the spectrum and color the atmosphere generally.

The trouble is that the known

impurities wouldn't suffice to produce the particular colors that characterize Jupiter. There must be some substance, or substances, in the atmosphere that produces the color, but we just don't know what it is.

What's more, we don't know why the Great Red Spot, in particular, is the color it is.

There are other storms on Jupiter, some of which are quite long-lived (though nothing like as long-lived as the Great Red Spot) and some of which are quite short-lived. The long-lived ones tend to be white, while those that are reddish tend to be short-lived.

The whiteness of the long-lived spots doesn't seem to be mysterious. It is thought to be an upwelling of ammonia that freezes after emerging from the hotter lower depths, spreading into a layer of ammonia ice.

Presumably, the material in the short-lived, reddish spots is lifted up from still lower layers and has more of the unknown color-producing substance that colors Jupiter's atmosphere generally. It is brought up in differing amounts, which would account for the fact that the redness brightens and pales with time.

The mystery is why the Great Red Spot is both reddish *and* long-lived, and why there is only one of it.

Perhaps the Galileo probe, which is on its way to Jupiter, will be able to give us more information about Jupiter's atmosphere in general, and about the Spot in particular.

Would it help if we studied the other gas giants as well? Until the 1980s, this was impossible since Saturn, Uranus and Neptune were so far away that astronomers could not make out the details of their surfaces to any but the slightest degree, if at all.

However, Voyagers 1 and 2 skimmed by Saturn in 1980 and 1981, and Voyager 2 went on to visit Uranus in 1986 and Neptune in 1989. Astronomers got a close-up view of each of these gas giants.

The important thing about these farther gas giants is precisely that they are farther. This means that they get less energy from the Sun, and if it is solar energy that drives the atmosphere into turbulence, then it is to be expected that Saturn would be quieter than Jupiter, that Uranus would be quieter still, and Neptune the quietest of all.

If we set the amount of Solar energy received by Jupiter in a given unit of time over a given area of its surface, arbitrarily, as 33, then what Saturn gets is 10, what Uranus gets is 2.5 and what Neptune gets is 1.

Saturn has many puzzles about it. Although the second largest

planet, it has only 3/10 the mass of Jupiter and is the least dense of the planets — indeed, the least dense object in the Solar system. Its density is only half that of the other gas giants. This means that it undoubtedly contains a larger percentage of hydrogen than the others do, but why? We don't know.

Saturn also has an enormously complex satellite system, and something quite unique in the form of a magnificent ring system, bright and huge, that makes it, by general agreement, the most beautiful object in the sky. The other giants also have rings, but those are thin, dark, and puny — almost contemptible. Why Saturn should be so richly endowed we don't know.

Saturn, though slightly smaller than Jupiter, takes a bit longer to rotate. However, it turns quickly enough to set up a strong wind circulation. What is missing is Solar energy. It gets less than one third the energy from the Sun that Jupiter does.

Its surface is a pale yellow, which presumably means that although it may have the same coloring material found in Jupiter's atmosphere, this material is frozen out to some extent (Saturn's visible cloud deck is at a lower temperature than that of Jupiter, of course) or is more effectively diluted by overwhelming quantities of hydrogen.

Saturn has storms on its surface, too, but Voyager 2 was only able to spot three of any size. They were oval, like Jupiter's Spot, and only faintly colored. The largest one was about 5000 kilometers (3000 miles) east and west and about half of that north and south. This makes it only about 1/30 the size of the Great Red Spot of Jupiter. It is a storm that is only (roughly) the shape and size of the United States.

Of course, since it was observed only by Voyager 2, we have no idea how long-lived it might be.

Uranus and Neptune are both blue planets. They are so cold that almost all the trace components of their atmospheres are frozen out. If there is the substance present that gives Jupiter and Saturn its color, it is ineffective in the outer gas giants. There the only gases of importance in the atmosphere are hydrogen, helium, and methane. Methane absorbs the red end of the visible light spectrum when present in quantity, and therefore reflects mostly bluish light. That is what gives Uranus and Neptune their colors. The two blue planets are very much alike in size and mass, and are virtually twin planets, as are Earth and Venus, closer to the Sun.

Uranus gets only 1/13 as much solar energy as Jupiter does and only 1/4 as much as Saturn. Therefore, if Saturn's surface is quieter

than Jupiter's, Uranus's surface ought to be quieter still, and so it is. When Voyager 2 passed Uranus, what it saw was a calm, almost featureless surface.

Uranus has its puzzles, of course. Its axis of rotation is tilted 98 degrees to the plane of its orbit. This means that it is rotating virtually on its side and, since it revolves about the Sun in 84 years, almost every point on its surface, except for regions within 8 degrees of the equator, gets 42 years of "day" and 42 years of "night." All its satellites rotate about it along its equatorial plane so that they move up and down, so to speak, rather than left to right, and so do the ten thin rings of debris that surround the planet. Its magnetic field is oriented at an enormous angle to the axis of rotation. We don't know what causes these anomalies.

As Voyager 2 sped on to Neptune, astronomers were confident that Neptune would also be dead quiet. After all, it receives only 2/5 the Solar energy that Uranus does, only 1/10 that Saturn does, and only 1/33 that Jupiter does.

Their confidence turned out to be misplaced. Neptune was wild. Not only did it have an atmospheric circulation that was as turbulent as that of Jupiter (if not more so) but it had a "Great Dark Spot."

The Great Dark Spot has only about 1/8 the area of Jupiter's Great Red Spot, but that still makes it as large as Africa and Europe put together. It is just as large for Neptune's size as the Great Red Spot is for Jupiter's size.

What's more, the Great Dark Spot has the same shape as the Great Red Spot, and is located in the same place — 20 South Latitude. Here, too, there is nothing similar in the northern hemisphere.

There are differences, of course. Neptune's Spot is more loosely constructed than Jupiter's and wobbles more. Its color-contrast with its surroundings is not as great.

The great mystery, though, is why the Great Dark Spot is there at all. Where does the energy come from that maintains it? It can't be solar energy, so it must be the internal heat of Neptune rising to its surface. But why does it do so on Neptune and not on Uranus, which is its virtual twin.

More than ever, I am curious to know why there is only *one* great spot on Jupiter and on Neptune, and why it is located in the southern hemisphere and not in the northern — and why there is no corresponding object on Saturn or Uranus.

Isn't it delightful that the more scientists learn, the more fascinating and puzzling the mysteries grow?

NOTE: Since this was written, an enormous storm was spotted on Saturn, which temporarily spread a white cloud of frozen ammonia nearly all the way about the planet.

SCIENCE

ISAAC ASIMOV

ROYAL GAMMA

WHEN I was young I took poetry very seriously, but, of course, what they taught me at school in those happy, happy days had rhyme and meter and could be understood.

Thus, in Thomas Gray's "Elegy Written in a Country Churchyard" (1750), there is a famous quatrain that goes:

Full many a gem of purest ray serene
The dark unfathomed caves of ocean bear:
Full many a flower is born to blush unseen,
And waste its sweetness on the desert air.

How many young people must have mooned over these lines, thinking of themselves, tearfully, as the hidden gem, the wasted flower, the unappreciated bit of perfection!

I will not hide from you the fact that this thought sometimes occurred even to me. You wouldn't think that this would be possible, considering that everything I think, say, and do finds its way into my stories and essays and gets published. No one wastes less sweetness on any desert air than I do, you might well imagine.

And yet there is such a thing as sparkling, spontaneous wit, of which I am a true master, and it is rarely appreciated.

I was at a meeting of the Gilbert & Sullivan Society a couple of weeks ago, and we were community-singing from "The Sorcerer." The last song we sang was "Now to the banquet we press," and there was a short colloquy between the song-leader and the pianist as to the key. The leader said, firmly, "The song is in A-major."

I promptly called out from the audience, "When I was in the army I had an officer who was A-major."

And a silence like unto death fell on everybody, and even my

dear wife, Janet, looked at me with something akin to loathing. I was the only one who laughed. It was one more case of sparkling, spontaneous wit wasting its sweetness on the desert air.

I must admit that I try, whenever possible, to exercise some s. s. w. on the titles of these essays. For instance, in the Gilbert & Sullivan play, "Princess Ida," one of the characters is King Gama, a snarling, nasty misanthrope. The play starts with everyone watching for Gama's appearance, and the opening chorus begins:

Search throughout the panorama,
For a sign of royal Gama,

Well, if you add an M to the royal name, you will find that those two lines represent, quite precisely, the subject of this essay, which I therefore call "Royal Gamma." And I bet no one appreciates that there's another batch of sweetness wasted.

The information available to us from the Universe reaches us by way of particles that stream from out there to down here, and these fall into two classes: 1) particles with mass and electric charge, and 2) particles with neither mass nor electric charge.

In the first category are such things as speeding electrons, positrons, nuclei and antinuclei. Of these, the electrons, positrons, and antinuclei are few and, as far as I know, are of no great significance. The nuclei (mostly protons) make up the energetic cosmic ray particles, and I dealt with them in my essays "Out of the Everywhere" and "Into the Here" (November and December 1988).

The charged particles are, in any case, of limited value because, being charged, they follow a path that curves in response to the magnetic fields that litter the Universe so that we have no idea as to their point of origin.

The uncharged, massless particles are not affected by magnetic fields and, being massless, travel at the speed of light, so that they are affected only very slightly by gravitational fields. The result is that we can know their points of origin very well.

There are three types of massless particles that bathe us in vast quantities, and they are: gravitons, neutrinos, and photons. Of these, gravitons have yet to be successfully detected, and neutrinos, while detectable, are only barely so. Consequently, what it boils down to is that the major source of information that we receive from the Universe consists of photons.

Photons differ among themselves in energy content, and, until the early 1900s, they were thought

of as consisting of waves, with the wavelength decreasing as the energy content increased.

Going down the line of photons from those with the longest waves and least energy, to the shortest waves and most energy, we have: radio waves, microwaves, infrared radiation, visible light (red, orange, yellow, green, blue, and violet, in that order), ultraviolet radiation, x-rays and gamma rays.

Until 1800, the only photons known were those of visible light, and every bit of information obtained from the Universe was through the mediation of that light. In the early 1800s, infrared and ultraviolet radiation were discovered; in the late 1800s, x-rays and radio waves were discovered; and everything else came in the 1900s.

All the different photons are of informational value now. In fact, we have learned more through a study of radio-wave photons than would ever have been dreamed possible, if astronomers had been stuck with visible light alone. In this essay, however, I'm going to talk about gamma-ray photons.

Since gamma rays are the most energetic of the known photons, they can only be produced by very energetic processes. They were first detected among the radiations given off by radioactive atoms, something that was itself detected only in 1896.

Some of the radiations were bent gently in one direction by a magnetic field, and they were called "alpha rays" from the first letter of the Greek alphabet. Other radiations were bent sharply in the other direction, and they were "beta rays" from the second letter of the Greek alphabet.

From the nature of the bending, it was clear that the alpha rays consisted of positively-charged, rather massive "alpha particles," while the beta rays consisted of negatively-charged, rather light "beta particles." It was not long before the alpha particles were identified as speeding helium nuclei, and the beta particles as speeding electrons.

In 1900, a French physicist, Paul Ulrich Villard (1860-1934), noted that some of the radiations emitted by radioactive atoms were not affected by magnetic fields at all. He called them "gamma rays" from the third letter of the Greek alphabet, and clearly they did not possess an electric charge.

The question was whether gamma rays were uncharged particles or uncharged waves. It was not understood at the time that every particle had wave properties and every wave had particle properties, and that you detected whichever one of these two aspects you were

trying to detect. As energy decreased the wave properties of photons increased in prominence; as energy increased the particle properties did.

Gamma rays are so energetic that their particle properties are easier to find than their wave properties are. When they were first discovered, however, no such things as electrically-uncharged particles had yet been detected, and so every effort was made to try to demonstrate the wave character of gamma rays.

In 1914, the British physicist Ernest Rutherford (1871-1937) succeeded. He showed that gamma rays could be diffracted by crystals just as x-rays could be, and by then x-rays were known to possess wave properties.

Since the gamma rays are even more penetrating than x-rays, they are, on the whole, of shorter wavelength and higher energy, but the two types of photons fade into each other. The least energetic gamma rays produced by nuclear transformations overlap the most energetic x-rays produced by electron collisions. Where they overlap, there is no real distinction between them except in the manner of their origin.

Gamma rays have wavelengths that run from 10^{-10} to 10^{-14} meters, so that the most energetic ones have wavelengths only a hundred-millionth as long as those of visible-light photons.

In 1923, the American physicist Arthur Holly Compton (1892-1962) was able to show that very energetic photons, such as those of x-rays and gamma rays, possessed properties characteristic of particles. In that same year, the French physicist Louis, Prince de Broglie (1892-1987) showed that undoubted particles, such as electrons, had to have wave properties, and, in 1925, the American physicist Clinton Joseph Davisson (1881-1958) actually detected the wave properties of the electron.

From then on, physicists stopped speaking of waves and particles as though they were mutually exclusive and began to understand the subatomic world in terms of quantum mechanics.

Since there are processes on our puny little planet that are energetic enough to produce gamma rays, we can be pretty sure that, in the Universe as a whole, there must be gamma-ray production here and there on an enormous scale. If so, some of those gamma-ray photons must eventually reach Earth.

So they do, but there's a catch. Energetic photons reach the upper atmosphere first and, tearing through, do enormous damage to individual gas molecules, but, in

the process, undergo large changes themselves. For this reason, x-rays and gamma rays produced by cosmic events do not reach Earth's surface as such. Even after the existence of such energetic photons was known, then, their production outside Earth remained undetected until such time as human beings could send rockets beyond the atmosphere so that they could detect radiation while it was still speeding through the vacuum of space.

The American astronomer Herbert Friedman (b. 1916) began to look for x-rays in space soon after World War II, when V-2 rockets were used to fire instruments to record heights above the Earth's surface.

In 1949, he demonstrated that the Sun emits x-rays, and, by 1956, he showed that one source was the solar flares, energetic explosions that take place now and then on the solar surface. In 1958, while observing the Sun during an eclipse, he was able to detect x-rays being given off by the solar corona.

By 1963, the Italian-American physicist Bruno Benedetti Rossi (b. 1905) was able to detect x-rays from sources other than the Sun, and with that Friedman began a systematic search of the sky for x-ray sources and began to find them, too.

In 1961, the rocket "Explorer XI" was the first to detect the existence of gamma rays in open space. By 1968, the rocket "OSO-3" found that the Milky Way was a source of gamma rays.

With that, the search for gamma rays began, too. The heavens were searched systematically for gamma-ray sources. By 1972, a rocket, "SAS-2," prepared the first rough map of the gamma-ray emission from different parts of the Milky Way.

Such maps have their shortcomings. Typically, the gamma rays can be pinpointed only within a circular region some four times the area of the full Moon. The result is that of the gamma-ray sources that have been located, few can be pinned down to an actual object that can be seen by some means other than gamma-rays. There are too many possible objects within the circle. The result is that studying gamma-ray sources is like trying to look at things through frosted glass.

Right now, astronomers are working on a "Gamma Ray Observatory" that will weigh 17 tons and that, it is hoped, will some day be put into orbit by a shuttle craft. It will be designed to detect gamma rays over the full range of energies and to determine their point of origin with greater precision than is now pos-

sible. It should be able to pin things down to a tight circle only 1/60th the area of the full Moon. That will improve the sharpness of vision by some 240 times, clarifying the frosted glass enormously.

This is not as easy as it sounds. The more energetic the gamma-ray, the more pronounced are its particle characteristics and the more difficult it is to distinguish it from cosmic ray particles. The trouble is that the Universe is much richer in cosmic ray particles than in gamma rays, so that scientists are trying to detect a few fugitive photons smothered in a large array of all-too-similar charged particles.

Fortunately, the two types of energetic objects are not exactly identical. Each one produces changes that the other does not, and the Gamma Ray Observatory will be designed to reject any cosmic ray particles it detects and report only on the gamma rays — it is hoped.

But suppose we do locate gamma rays, study their energies, and pinpoint their places of origin. What can we possibly learn from them except that those photons are coming from there to here?

The answer to that is that we may learn some details of very energetic phenomena that we wouldn't learn much about in any other way.

For instance, the most energetic phenomenon we are able to observe directly is a supernova explosion. It comes about this way.

Stars, to begin with, are mostly hydrogen. At the enormous temperatures and pressures at their core, the hydrogen fuses to helium, producing energy that keeps a star like our Sun shining for some ten billion years in fairly stable fashion.

A large star has a larger hydrogen supply than a small star, but the large star uses that larger hydrogen supply at so much more rapid a rate that it doesn't last as long as the small star's smaller supply does. The larger and more massive the star, the more rapidly it goes through the stages of stellar evolution. While our Sun may last in stable condition for ten billion years, a really massive star may not last longer than a few million years.

As a star ages, the core becomes richer and richer in helium. Helium, being denser than hydrogen, accumulates at the core and continues to compress and grow hotter. Eventually, it becomes hot enough to fuse to more massive nuclei, which in turn eventually fuse to still more massive nuclei for successive doses of energy. (All fusions past helium add minor quantities of energy, however, compared to that available from the fusion of

hydrogen itself.)

Ordinary stars, like our Sun, don't reach very far into the stages of later fusion. They start swelling because of the internal heat, become monstrously large so that the surface cools down. They become red giants and eventually collapse into white dwarfs, blowing off a relatively insignificant portion of their outer layers (still chiefly hydrogen). They become "planetary nebulas," in this way. The exploded outer layers of hydrogen and helium expand into outer space, and the contracted portion remains a white dwarf, slowly cooling, for billions of years.

Really large stars, however, have enough gravitational pull to hold themselves together through many fusions. Eventually, such a giant star comes to resemble an onion, with an outermost layer still mostly hydrogen, but inside that a layer of helium; inside that one of carbon, nitrogen and oxygen; inside that a layer of silicon, magnesium and aluminum; and inside that, a layer of nickel, cobalt, and iron.

Iron is as far as any star, however massive, can go, for iron is the most stable of all the elements. It cannot fuse any further and produce energy. In fact, it would have to *absorb* energy to fuse.

The result is that a massive star suddenly has no further source of sufficient energy to keep it expanded against the pull of its own mighty gravitational field. It collapses, but not just as an ordinary red giant does. The contraction of a giant star is far more catastrophic. In a very short period of time, its central regions rush together, and the outer regions explode with unimaginable fury, spraying heavy nuclei all through space. These are not nuclei merely up to iron, but include still heavier nuclei formed by the influx of the energy of the supernova explosion, all the way to uranium and beyond.

The interstellar dust clouds are thus polluted with these heavy nuclei, and when they collapse into stars it is as "second-generation stars" that contain much of the material that formed in the centers of first-generation stars that exploded as supernovas. The Sun is such a second-generation star, and every bit of matter on Earth and in our bodies — except for hydrogen and helium — was once at the center of a giant star.

What we don't know is the exact details of the explosion — just what nuclei are formed and how they decay. That kind of knowledge, if we could obtain it, might tell us a great deal about what goes on inside stars, about the course of stellar evolution, about the past and future of the Universe, and

even about our own Solar system, our own planet, and our own bodies.

How do we find out?

Well, that initial burst of inconceivable energy is stored, in part, in the form of massive, unstable nuclei, huge quantities of them, which proceed to decay and undergo radioactive change, giving up, little by little, the energy stored in their formation. Some of these nuclei give off highly energetic gamma rays as part of the breakdown process.

It is this radioactive breakdown that keeps the supernova glowing for months and years amid the ashen aftermath of the explosion, and if we could detect gamma rays that are unmistakably from a supernova remnant, and follow the decline in the rates of their production with time, we ought to be able to deduce with some precision which nuclei were formed and in what relative quantities.

In short, we might learn much more about the intimate mechanics of the supernova in a relatively short time of gamma-ray studies, than we could have learned with an infinity of watching by visible light.

It is for this reason that it is intended to have the Gamma Ray Observatory zero in on all the supernova remnants we know of — some quite recent like the February 1987 supernova in the Large Magellanic Cloud (the nearest to us in almost 400 years) and others that may be nearly a thousand years old, like the Crab Nebula, and some that are even millions of years old. By studying them at all ages, we will, in effect, get an extended "motion picture" of what happens in such explosions.

This is not to say we haven't already made a beginning, even without the Gamma Ray Observatory. A close study of the recent Magellanic supernova has detected gamma rays of the type to be expected from the decay of cobalt-60. Astronomers hope to go much farther than this with the Observatory.

What a supernova leaves behind after the explosion are extremely condensed objects: either neutron stars or black holes.

Neutron stars were discovered in 1969; at least, *some* were. A neutron star has enormously intense gravitational and magnetic fields. Speeding electrons and photons can just barely get away from a world in which only objects traveling at nearly the speed of light can make it to outer space. And even then, they can only escape in the region of the magnetic poles.

The magnetic poles are not always located at or near the rotational poles. Therefore, as the neu-

tron star rotates (at rates of anywhere from 4 seconds to a few thousandths of a second), the magnetic poles whirl around, spraying electrons and photons as they move.

Some of these neutron stars send out the sprays in such a way that they strike the Earth, and those neutron stars we detect chiefly by the pulses of microwave photons they emit. The pulses come very rapidly and with extreme regularity. Neutron stars that are detected by astronomers as objects producing pulses of photons are called "pulsars."

We can make deductions concerning pulsars from occasional sudden changes (or "glitches") in the pulsation periods and, barring such changes, from the slow but steady lengthening of the period. Some neutron stars send out visible-light photons so that, as they turn, they blink on and off several times a second, like a Christmas-tree light. The neutron star inside the Crab Nebula is such an "optical pulsar."

At least two pulsars have been caught occasionally emitting gamma ray photons. At least, the photons *seem* to be coming from there. If the Gamma Ray Observatory can pinpoint such emissions more exactly, and can measure the energies and time the pulses, we may learn much more about pulsars, and neutron stars generally, than we now know. This would be another step in understanding the intimate details of supernova explosions.

Then there are the quasars, objects whose existence was first noted in 1963. They are the farthest class of objects known, the nearest being a billion light-years away, while the farthest is well over ten billion light-years away.

They are also the most luminous objects known, some blazing with a glow of a hundred galaxies. They are, in fact, galaxies, but so far away that, except under the most favorable conditions with the most advanced instruments, one sees just the luminous centers that are only a few light-weeks across.

It is difficult to understand how it is possible for an object so small to be so luminous and to deliver so much energy. The quasar, shining for indefinite periods, makes the supernova look like a damp firecracker, and we don't know exactly what's happening there. The best guess or, at any rate, the most popular one is that there is an enormous black hole at the center, one that is swallowing stars whole, and that the energy is the conversion into radiation of the vast kinetic energy of stars spiraling into bottomless holes. Still, that is

only a guess.

One of the quasars, the nearest, 3C273, is known to be a gamma-ray emitter. Apparently, half its total energy emission is in the form of gamma rays. A close analysis of those gamma rays may tell us more about what is going on in the core of the quasar, and a study of other quasars (hundreds are now known) may spot gamma rays from other such sources.

In fact, there may be black holes at the center, not only of quasars, but of more ordinary galaxies ("active galaxies") that seem to have catastrophic events going on in their cores. Gamma-ray studies of those cores may be illuminating, too.

There are some astronomers who think that black holes exist at the center of most, if not all galaxies, that black holes may possibly be the cores about which the galaxies formed in the first place. There seems to be considerable suspicion that the center of our own Milky Way Galaxy possesses a black hole. Certainly, there is a spot in the constellation of Sagittarius that is particularly active, and it undoubtedly represents our own Galactic center. That center is undoubtedly a gamma-ray source. And what about gamma rays that have been detected here and there, all along the Milky Way?

In fact, we're still in a state of uncertainty as far as black holes are concerned in general. There is some reason to think that relatively small black holes make up part of certain double-star systems, largely through studies of x-rays given off by matter spiraling from the normal star of the pair into the presumed black hole. It would be a lot more convincing if we could also spot gamma rays, which might well be the last cry of the disappearing matter.

Perhaps the most puzzling aspect of gamma rays are "bursters," sudden bursts of gamma rays that occur at unpredictable times in unpredictable places and for only brief periods. While they're going, however, the bursters deliver more gamma-ray energy than all the steadier sources combined. We are not sure what these can possibly represent, but it is hard to believe that we would fail to discover something quite new about the Universe, if we studied bursters closely and came to understand them.

So — search throughout the panorama for a sign of royal Gamma.

SCIENCE

ISAAC ASIMOV

THE LEGACY OF WINE

I AM SOMETIMES accused of being a scientist. I can't actually deny this because I have the basic credentials. That is, I have a doctorate in chemistry and I bear the title of "Professor of Biochemistry" at a first-class medical school.

But that ends it. I haven't worked at being a scientist since 1958, and even in the period from 1942 to 1958, when I did work as a professional chemist, I accomplished virtually nothing.

Somewhat to my own astonishment, I turned out to be a complete failure in research; and it is to my credit, I think, that I recognized that little fact quite early in the game. I was the living embodiment of the old bromide, "Those who can, do; those who can't, teach."

I began to concentrate on teaching and quickly realized that there, at least, I was world-class. The medical school kicked me out for spending my time teaching instead of researching (though I stubbornly held on to my title) but I continued teaching in my lectures and in my books.*

Teaching is, I suppose, a second-class occupation for a scientist and will never win me a Nobel Prize, but I have always felt it was far better to be a first-rate teacher than to be a mediocre researcher. I tried to explain that to the director of the Medical School, with the accompanying statement that if there was one thing the school didn't need, it was one more mediocre researcher — which got him furious, for some unaccountable reason, and made it certain I would be fired.

But I'm satisfied. I have had uncounted numbers of young people tell me they were introduced to science by my books and that it was those books that persuaded them to tackle a scientific career of

* *I also turned out to be a very good writer, but that's beside the point.*

their own. And if I have never accomplished anything in science myself, I am certain that many of my intellectual children have and will.

In the days when I was working as a mediocre researcher, my field of specialization was enzymes. In fact, my Ph.D. dissertation dealt with an enzyme named tyrosinase, and the title of that dissertation (hold your breath now) was: "The Kinetics of the Reaction Inactivation of Tyrosinase During Its Catalysis of the Aerobic Oxidation of Catechol." It was not one of my catchier titles.

I have always thought of that dissertation as probably the least important ever written in the chemical sciences, and I've even been a little proud of that. It's a distinction, after all.

In honor of that dissertation, written 43 years ago, I think I ought to devote one of my essays in this series to enzymes. Here goes:

The story of enzymes begins with an accidental prehistoric discovery that must have been made in numerous places. In the absence of refrigeration, fruits and moistened grain would sometimes undergo peculiar changes. The process eventually came to be called "fermentation" from a Latin word for "boil" because, in the process, bubbles of gas formed.

Driven by thirst or hunger, human beings sometimes ate the fermented material and found, to their delight, that: a) it tasted good, and b) it made them feel good, if taken in moderation. What prehistoric people didn't know was that water was frequently contaminated with disease-producing microorganisms that would not live in wine or beer, so that it was actually safer to drink the fermented material than ordinary water.

Nor was this an entirely human phenomenon, for birds and mammals would sometimes greedily feed on fermented fruits and show all the signs of happy intoxication.

Flour could also be made to ferment, and the appearance of bubbles would puff it up so that it could be baked into soft, porous bread, rather than into a flat, hard substance.

By 1800 B.C., fermented drinks had come to be so popular that special laws had to be enacted to dictate the handling of misdeeds committed under the influence of too much beer.

What's more, it was discovered that if a little of the fermenting fruit juice was added to fresh fruit juice, the new batch would ferment quickly. It was assumed that there was a substance called a "ferment" in the fermenting material that

would do the trick.

A bit of bread being raised by fermentation, if added to a new batch of flour, would quickly cause it to rise, too. The material in the fermenting bread that did this came to be called "leaven" from a Latin word meaning "to raise." Thus, we speak of "leavened bread" (the ordinary bread we eat) and "unleavened bread" (the matzos eaten by observant Jews during the Passover season).

The ability of leaven to cause the raising of fresh, unleavened flour is referred to by St. Paul as a metaphor for the manner in which the sin of one man can corrupt an otherwise blameless group. "Know ye not," he says, "that a little leaven leaveneth the whole lump?" (1 Corinthians 5:6).

Another name for "leaven," by the way, is "yeast," which has been traced back to a Sanskrit word meaning "to boil." This has come to be the most common name for leaven and ferment.

The ancients, of course, had no idea how grape juice, for instance, was changed into wine. It just happened. The beginning of knowledge in this respect came with the medieval alchemists, some of whom were earnest and capable, and made important discoveries that laid the groundwork for future chemistry.

Alchemists noted that a number of substances, upon heating, would bubble and liberate vapors of "spirits" (from a Latin word meaning, among other things, "vapors"). Gradually, they learned how to trap some of these spirits, cool them, and allow them to condense to liquids.

When they heated wine, they got "spirits of wine." (For this reason, we still speak of alcoholic drinks as "spirits," in consequence.) When the spirits of wine were cooled, what was obtained was something that looked like water but had a winy smell. An even more important difference was that the spirit burned so that one early name for it was "aqua ardens," Latin for "burning water."

The Arabs, who were among the great alchemists of the Middle Ages, referred to very fine metallic powders as "al kohl." What could be finer than the vapors formed by heating some liquid. Therefore, it became possible to speak of "al kohl of wine" rather than "spirits of wine." The phrase "al kohl" became "alcohol." (Nowadays, we know that there are a vast number of different related compounds all of which can be referred to as alcohols. The specific one in wine is "ethyl alcohol" so-called for reasons we don't have to go into here.)

Once the alchemists discovered alcohol, it was not difficult to deter-

mine that it was the ingredient which produced the intoxicating effect.

Alcohol boils at a lower temperature than water does, so if wine is distilled, more alcohol than water is vaporized to begin with, and the early vapors, if condensed to liquid, contain more alcohol than the original wine did and produce more intoxication.

About 1300, a Spanish alchemist, Arnau de Villanova (1235-1312), distilled wine and produced the stronger liquor, brandy, in the process. (Brandy is a corruption of "brandwine," meaning "fire-wine" probably because it was produced by heating, and also, perhaps, because of its fiery effect on the body.) In the same way, fermenting grain could be distilled to produce "whiskey" (from an old Gaelic word, "usquebaugh").

In the mid-1300s, the worst pandemic on record struck the world. It was a form of the pneumonic plague and was called the "Black Death." It may have killed one-third of humanity, a percentage slaughter greater than anything we know of before or since. It was extremely contagious, and could sometimes kill within twenty-four hours of the appearance of the first cough. Humanity, with no knowledge as to the workings of infectious disease, and with only a dim awareness of personal hygiene, was helpless. The wonder is not that one-third died, but that two-thirds survived.

In any case, people snatched at straws, and the word went about that hard liquor would prevent the infection. People therefore took to drinking the newly discovered brandy and whiskey. It had not the slightest effect on the Black Death, one way or the other, but it made people less concerned about the disease, so it did serve a purpose.

In this way, a pall of intoxication and alcoholism descended upon Europeans and upon those with whom they eventually came into contact. It was a pall that has never lifted.

The study of the process of fermentation was simplified by the French chemist, Antoine Laurent Lavoisier (1734-1794). Instead of working with fruit juice, he worked with a sugar solution. He found that it was the sugar solution, not the fruit juice generally, that was fermented. In the process of fermentation, the sugar was converted to alcohol and to a gas. The latter turned out to be carbon dioxide, well-known by then. It is the bubbles of carbon dioxide that appear in fermenting flour and that raise it to form leavened bread.

Now the question is: What is the yeast that seems to be essential

to the process of fermentation?

From the facts that a small quantity of yeast can apparently multiply; that "a little leaven leaveneth the whole lump"; that it can be transferred from flour to flour and from juice to juice so that a small quantity can eventually ferment all the fermentable material in the world, one can only conclude that yeast must be alive. How else could it grow in this fashion?

That conclusion is obvious, however, only in hindsight, and hindsight comes only with the passage of time.

To be sure, as long ago as 1676, the Dutch biologist Anton van Leeuwenhoek (1632-1723) had ground tiny lenses, through which he could see living "animalcules" (we call them "microorganisms" today) in pond water. He showed the existence of microscopic forms of life.

However, Leeuwenhoek's microorganisms swam about vigorously while yeast just lay there, so that it was difficult to assume that yeast, too, was a microorganism.

Besides that, the early microscopes were rather crude instruments. Their lenses reflected the different wavelengths of light differently so as to produce tiny spectra, or rainbows. The result was that any attempt to focus sharply on any tiny object always surrounded it with a small halo of colored light and obscured the result. In consequence, many microscopists saw objects that arose largely out of their imagination and reported on them. These could not be confirmed by other microscopists, and the field fell into some disrepute.

It was not until 1830 that the British optician Joseph Jackson Lister (1786-1869) developed an achromatic lens (one that did not produce a spectrum) for use in microscopes. It was only then that such instruments could be used effectively, and, even so, few non-microscopists cared to take microscopic data at face value.

Many chemists, then, dismissed the possibility that yeast, which made its appearance as a quiescent sediment, with no more obvious life in it than a layer of mud, could possibly consist of living microorganisms. Instead, they looked for a straightforward chemical explanation of fermentation.

Outstanding among these was the German chemist Justus von Liebig (1803-1873), who did not have a good chemical theory of fermentation, but, by 1839, had worked out a semi-mystical, not very detailed picture of the process. Since he was a great chemist, however, his views carried conviction.

Nevertheless, just a year earlier, in 1838, a French engineer, Charles

Cagniard de la Tour (1777-1859), had studied yeast under the new achromatic microscope and could see that it was composed of tiny spherules. What was far more important was that some of these spherules were budding, producing other spherules. His conclusion was that yeast was a living, growing microorganism.

In 1839, the German physiologist Theodor A. H. Schwann had advanced the "cell theory" of life, claiming that all life consisted of tiny bits of protoplasm, separated from other such bits by fine membranes. He, independently of Cagniard de la Tour, also recognized the living nature of yeast and proclaimed it to consist of yeast cells.

Chemists still scorned the microscope, however, and remained under the influence of Liebig. Yeast, as a possible life-form, was dismissed for nearly twenty years.

Then came the French chemist Louis Pasteur (1822-1895). He had already established a considerable reputation by 1856, when a representative of the French wine industry asked Pasteur for his help. Wine-making was an art that didn't always work, and for some reason fermenting grape-juice was turning sour and threatening one of the great industries of France.

Pasteur travelled to the wine district with his microscope and studied samples of fermenting juice that were indeed forming wine. He found it contained yeast cells, which he caught in the process of budding, just as Cagniard de la Tour had done eighteen years earlier.

On the other hand, when Pasteur studied fermenting fruit juice that was turning sour, he found that it contained smaller cells that had the capacity of turning sugar into lactic acid (the acid characteristic of sour milk).

It was clear to Pasteur that fermentation was brought about by living cells and that, moreover, there was more than one variety of such cells producing more than one variety of product.

Apparently what happened was this. If both types of cells were present, the ordinary yeast cells would produce the wine and, when enough alcohol was present, it would kill those cells. The smaller cells, however, would remain alive and would act to change the sugar further to lactic acid.

Pasteur suggested the following about 1860. Once the wine was formed, it should be heated gently to 120 F. That would kill the lactic acid producers and the wine would stay sweet. The vintners were horrified at this suggestion, but desperation drove them and they tried it.

It worked! Pasteur had invented the process of "pasteurization."

(Pasteur went on to generalize his findings and developed the "germ theory of disease." This worked, too, and Pasteur became the most famous scientist in the world.)

Pasteur's demonstration that yeast consisted of living cells was so clear and so irrefutable that the chemists who maintained that yeast was not alive were forced to back down.

Even Liebig had to admit that yeast consisted of living cells. He maintained, however, that what did the work of fermentation was not the living cell itself, but something within it that was not alive and that was the fermenting vehicle.

In this, Liebig was absolutely right, but now it was Pasteur, not he, who bore the weight of prestige, and Pasteur carried the day.

Yet there were examples of non-living ferments that were well-known by 1860.

Yeast was acting as a "catalyst" (see my essay, "The Haste-Makers, F & SF, September 1964). It enormously hastened, by its presence, a reaction that would take place with only glacial slowness in its absence. What's more, yeast, like the typical catalyst, did not seem to take an obvious part in the reaction. The sugar turned to alcohol and carbon dioxide while the yeast remained yeast.

Could this happen only in the presence of living organisms, as Pasteur claimed?

The fermentation of sugar to alcohol, however, is not the only reaction catalyzed in or by life-forms. When grain is fermenting, for instance, the starch granules it contains were converted into sugar molecules. As long before as 1833, a French chemist, Anselme Payen (1795-1871), had found that whatever catalyzed the reaction was present in the watery material surrounding the fermenting grain.

He worked with the watery material and obtained a preparation that contained no living microorganisms in it, but that hastened the conversion of starch to sugar enormously. He called the active principle "diastase" from a Greek word for "separation," presumably because he had separated it from the living cell.

This name eventually established the "-ase" suffix for all organic catalysts of the sort, though a few, isolated very early on, developed names with other suffixes that became too well-known to change.

In 1834, Schwann, who was to help pioneer the notion of yeast as a living microorganism, isolated a material extracted from stomach linings that disintegrated and digested meat. It, too, while obtained from living material, was not itself living. Schwann called the catalyst "pepsin"

from the Greek word for "digestion," and the name stuck — one of the few organic catalysts that does not have the "-ase" ending.

Diastase and pepsin were examples of "soluble ferments," ferments that were non-living molecules, soluble in water. By 1860, then, when Pasteur had established yeast as a living catalyst, there were not wanting those who maintained that all ferments were actually soluble ones, and that those that did not seem to be so had merely not yet been effectively isolated from the cells within which they were bound. A Polish chemist, Moritz Traube (1826-1894), maintained this, for instance.

Traube's views could not stand up against those of Pasteur, however.

The French chemist Pierre E. M. Berthelot (1827-1907) tackled the yeast-cell bastion. In 1860, he mashed up yeast cells and obtained out of them a soluble ferment that was capable of breaking down sucrose (a double-sugar, familiar to us as ordinary table sugar) into its single-sugar components, glucose and fructose.

Sucrose twists the plane of polarized light in a clockwise direction, while the mixture of glucose and fructose twists it in a counterclockwise direction. The process of breakdown inverts the direction of twist, and Berthelot therefore called his soluble ferment, "invertase." As a result of this experiment, Berthelot was converted to the view that all ferments were non-living, even when they occurred within a living cell.

Pasteur, however, held out. While admitting that invertase was a soluble ferment obtained from yeast, he pointed out that it catalyzed an almost trivial reaction, and had nothing to do with the fermentation of sugar to alcohol which, Pasteur insisted, could only be brought about by the intact cell.

Again, Pasteur prevailed, and chemists continued to make a firm distinction between soluble ferments and cell ferments. In 1878, in fact, the German physiologist, Wilhelm Friedrich Kuhne (1837-1900), suggested that confusion between the two would be eased by the use of different names. The catalytic substances that existed only in intact cells could still be called "ferments," but soluble ferments, he suggested, should be called "enzymes." This was from Greek words meaning "in yeast," since soluble ferments had properties resembling those of ferments in yeast.

(Kuhne was more successful than he could have guessed. His word, enzyme, came eventually to be applied to all ferments, whether

inside or outside the cell.)

Pasteur died in 1895, with his views still prevailing, but within two years they were completely exploded.

A German bacteriologist, Hans Buchner (1850-1902), was attempting to obtain substances from yeast that would be of immunological interest. He was not in any way concerned with the fermentation process.

The trouble he encountered was that when he mashed up yeast cells, the materials he obtained quickly underwent bacterial decomposition. What he needed was a preservative that would prevent bacterial growth.

He tried a number of preservatives, and one of them was sucrose. A surfeit of sucrose prevents bacterial growth. That's why jams and jellies are prepared. Not only does the high sugar content satisfy our sweet tooth, but it makes it possible to keep them on the shelf indefinitely without refrigeration.

Hans Buchner was shoving sugar into his yeast preparations, therefore, and, being uninterested in fermentation, didn't pay attention to the fact that bubbles were appearing.

Hans, however, had a younger brother, Eduard Buchner (1860-1917). Eduard was a chemist and, while vacationing, he visited his brother and noted the bubble formation in the sugar-filled yeast extract. Eduard, as a chemist, saw the significance of this at once and asked his brother if he might experiment with the material. Hans, who had always been a solicitous and helpful older brother, gave permission at once, and Eduard Buchner got to work.

The younger Buchner's first concern was to break up the yeast cells beyond redemption. To do this, he mixed the yeast with an equal weight of sand, then ground the mixture into a moist and muddy mess.

He wrapped this up in cheesecloth and put it in a hydraulic press that exerted several hundreds of atmospheres of pressure on the material. This burst any cells that had survived the grinding. Buchner next passed the mess through a layer of filter paper to remove any intact cells and cell fragments that, despite everything, might have remained.

In this way, he ended up with what we can only call "yeast juice," which was clear and slightly yellow.

He then added sugar to the yeast juice and, behold!, fermentation began, alcohol was produced, carbon dioxide was evolved, all in the entire absence of life. Buchner had isolated a soluble ferment (actually, as was eventually found, a complex

mixture of soluble ferments) that catalyzed the fermentation reaction.

This startling demonstration roused considerable opposition, of course, but that opposition faded. The experiment was easily repeated, more and more experimenters obtained Buchner's results, and the whole matter was simply irrefutable.

We can't tell what Pasteur would have said if he had lived, but the Pasteur Institute, which had been established in 1888 in Pasteur's honor, accepted Buchner's work.

In 1907, then, Buchner received the Nobel Prize in chemistry for what he had done. Undoubtedly, his brother would have shared the prize, but he died in 1902, at the age of only 52.

The younger Buchner went on to a tragic end. In 1917, he volunteered for active duty in the German army during World War I. He was 57 at the time, and had no business volunteering. Nor did the German authorities have any business allowing it. However, he joined and died on the Rumanian front within a matter of months, sacrificing a first-class scientific brain to no purpose.

(During the Franco-Prussian war, Louis Pasteur, then 48, tried to volunteer. The French authorities, showing some brains — perhaps the only brains they showed in that disastrous war — gently led him back to the laboratory, telling him that that was where he could best serve France.)

In this way, enzymes, the name now universally used for ferments of all kinds, took up their role in the consciousness of scientists as catalysts that control all the chemical reactions within the living cell. They are the manipulators of life and, in their numbers, see to it that all the reactions mesh in appropriate manner in different species of life, and in different individuals of a species.

Much, however, remains to be discussed.

What are enzymes, chemically, and how do they do their work? I will take that up next month.

SCIENCE

ISAAC ASIMOV

THE MARCH OF THE AMINO ACIDS

ONE OF my peculiarities (one which I believe I share with many men) is an affection for the possessions that have grown old — the older the better.

Women do not share this decent reverence for age. When they buy new clothes, they wear them on their way home. With me, it is just the opposite. Every once in a while, my dear wife Janet calls in our tailor, who takes precise measurements of me and manufactures suits, jackets, pants, and other articles of wear of high quality and enormous price.

There then follows everything but a fistfight as Janet tries to get me to wear my new clothes. When she isn't looking, I put on my good old decrepit articles of wear. After all, I'm accustomed to them.

It works with everything. The other day (it happened to be my 17th wedding anniversary, through sheer coincidence) I stopped off at the bank to clip some coupons I had long neglected. For this I had to hand over the key to my safe-deposit box, a key that was attached to a venerable key-case that was dear to my heart. I wouldn't say it was more than thirty years old.

I handed over the key, attached to the key-case, and the woman in charge of the safe-deposit boxes stared at it with a curled lip.

She said, "I should think, Dr. Asimov, that a man with as much money as you have could afford a new key-case."

I jumped a little. After all, do I need this from strangers?

I said, hotly, "I have a new key-case. Several. But this one isn't worn out yet."

"It is too," she said.

"It is not," I said, even more hotly. "Listen, I had a winter overcoat I loved that I had owned for thirty-five vintage years, and my wife went and gave it to the Salvation Army when I wasn't looking

and I've never gotten over it."

She wouldn't back down. She said, "Your wife was right."

"No, she wasn't," I exclaimed, energetically. "If I didn't love old things, I would get a new wife."

The woman burst out laughing and that ended the conversation, but I was still brooding when I got home. I fixed my dear wife Janet with a baleful eye and said, "A lucky thing for you that I love old things, old thing."

Since this was an odd greeting for a wedding anniversary, she asked what it was all about. I told her what had happened.

She laughed. She thought it was funny.

Women simply don't understand how men feel about things.

I love old essays, too. The first serious science essay I ever wrote for a science fiction magazine was entitled "Hemoglobin and the Universe," and it appeared in the February 1955 issue of *Astounding Science Fiction* — four and a half years before I started the present F & SF series.

It dealt, in part, with amino acid combinations, and in this present essay I'm returning to the subject and hope that I can treat it with the additional skill that 35 years of practice has brought me.

In doing so, I will, in the end, return to the matter of enzymes, the subject I dealt with in last month's essay.

In the early 1800s, chemists were doing their best to determine the chemical structure of various components of foodstuffs, and, in 1827, the British chemist William Prout (1785-1850) first divided those components into three chief classes. The first two of these classes were what we now call carbohydrates (sugars and starches) and lipids (fats and oils). We can dismiss them, for they need not concern us in this essay.

The third chief class was found most conveniently and commonly in egg-white or "albumin" (from the Latin word for "white"), and this class was therefore referred to as the "albuminoids."

In 1838, a Dutch chemist, Gerardus Johannes Mulder (1802-1880), decided that albuminoids were more complex in structure than either carbohydrates or lipids. Whereas the latter two seemed to contain atoms of carbon, hydrogen, and oxygen only, albuminoids contained not only those three elements, but also nitrogen atoms and, occasionally, sulfur atoms. Mulder tried to work out what the actual formula of albuminoids might be but, of course, got nowhere. The complexity of the problem was far beyond the chemical techniques of the day.

Nevertheless, the possible importance of albuminoids was clear, and, in 1838, the Swedish chemist Jons Jakob Berzelius (1779-1848) suggested that albuminoids be given a new name that would indicate that importance. He suggested "protein" from a Greek word meaning "of primary importance." Albuminoids have been known as proteins ever since.

However, if the overall chemical composition of proteins could not be determined in the early 1800s, it had become possible to break them down and obtain smaller pieces out of it.

As early as 1812, a German-Russian chemist, Gottlieb Sigismund Kirchhoff (1764-1833), had found that if he treated starch with sulfuric acid, he obtained a much smaller molecule out of it. This small molecule was sweet to the taste, so he named it "glucose" from a Greek word for "sweet." Other complex molecules were broken down in this fashion.

In 1820, the French naturalist Henri Braconnot (1781-1855) treated gelatin, an albuminoid substance, with sulfuric acid and obtained two small molecules out of it. One was sweet to the taste, so he named it "glycine." The other could be dried to a white powder, so he called it "leucine" from a Greek word for "white."

It took over a hundred years to obtain all the small molecules of importance. The last of them was "threonine," so-named because it turned out to be structurally related to a simple sugar named "threose." It was discovered in 1935 by the American biochemist William Cumming Rose (1887-1985).

It turns out that there are twenty different small molecules that can be isolated from all, or nearly all, proteins. They are not hugely different in variety, fortunately, or the problem of protein structure might have been too difficult to handle. Rather, they are all members of a particular group of compounds.

All these compounds have a basic skeleton consisting of two carbon atoms and a nitrogen atom (C-C-N). The nitrogen is part of an atomic grouping called an "amine" because it is chemically related to the common substance "ammonia." The carbon atom at the other end of the chain is part of an atomic grouping called a "carboxylic acid," because it contains a carbon atom and two oxygen atoms and has acidic properties. The whole molecule is therefore called an "amino-acid."

Attached to the central carbon atom of the amino acid is a group of atoms called a "side-chain." This varies from amino acid to amino acid. In glycine, the simplest of the

amino acids, the side-chain consists of a single hydrogen atom. In others, it consists of larger carbon-containing groups. Some of these are electrically neutral; some carry a positive electric charge; some carry a negative electric charge. Every one of the twenty amino-acids has a different side-chain; that is what makes them different amino-acids.

Granted that you can break down a protein molecule into amino acids, how do those amino acids fit together in the intact protein molecule? This problem was solved by the German chemist Emil Hermann Fischer (1852-1919) in 1907.

He was able to show that the amino group of one amino acid combined with the carboxylic acid group of another amino acid. This process was repeated till there was an entire chain of amino acids that had combined in this way. (A water molecule is eliminated at each joining, but we don't have to worry about chemical minutiae.)

The result is what is called a "peptide chain" from the Greek word for "digestion," since in the digestive process, proteins are broken down to such peptide chains to begin with, and to individual amino acids eventually.

Fischer was even able to put together eighteen amino acids into a peptide chain and to show that it could be digested into smaller fragments and eventually, into individual amino acids.

The peptide chain consists of a long chain of carbon and nitrogen atoms that would look like this -C-C*-N-C-C*-N-C-C*-N- and so on, extending considerable lengths in either direction. The asterisk after certain carbon atoms marks those to which a side-chain is attached.

The peptide chain, then, has a series of side-chains of different characters extending outward from the main chain. There are no limitations as to which amino acid can follow which, so there are no limitations to the order of side-chains that exist.

Once a peptide chain is formed, it folds up into a three-dimensional structure, the nature of the folding depending on the order of amino acids in any particular chain. The side-chains may, in some cases, exist inside the folding, but for the most part they are exposed on the surface which thus takes on a characteristic bumpiness, depending on the size, nature and order of the side-chains, and along the bumpiness there are positive and negative electrical charges scattered here and there.

Every different combination of amino acids produces a peptide chain that will, in turn, produce a

protein molecule with a surface of a distinctive nature. What we have to ask next is how many different surfaces are possible, for each different surface represents a protein molecule of slightly different properties from that of all others.

Since the nature of the surface depends on the order of the amino acids, let us suppose we begin with one each of the twenty different amino acids and ask how many arrangements we can have of those twenty.

The first amino acid can be any one of the 20; the second any one of the remaining 19; the third any one of the remaining 18, and so on. The total number of arrangements, then, is 20 X 19 X 18 X 17 X 16 X 15 X 14 X 13 X 12 X 11 X 10 X 9 X 8 X 7 X 6 X 5 X 4 X 3 X 2 X 1.

You are welcome to work out this product for yourself, but it may be less troublesome to take my word for it. The product is just over 7,280,000,000,000,000,000.

This sounds enormous and it is indeed enormous, even though it only involves one amino acid of each type. A protein molecule may well have a sizable number of each of the amino acids, which greatly increases the total number of arrangements possible. Of course, if you have five of a particular amino acid, each present in a certain position of the chain, it doesn't matter if those amino acids are switched about; whether there is one or another of the five identicals in a particular spot. Five amino acids can be rearranged in 120 different ways, so that the total number of arrangements that would exist if all the amino acids were different has to be divided by 120. This is true for every case in which a particular amino acid is found in the chain more than once, but it is a detail that can be handled without undue difficulty.

Let us suppose, for instance, that a protein molecule consists of a peptide chain that is 240 amino acids long (by no means unusually long for a protein) and that, just to simplify matters, the chain includes 12 each of the 20 amino acids. The total number of possible arrangements, then, is something I won't write out. Instead I will say that it is just about a 4 followed by 458 zeroes; that is 4×10^{458}.

This is enormously larger than the total number of particles in the Universe, and yet it by no means represents the full range of possible variations in protein structure. Protein molecules may be longer and shorter than 240 amino acids; and the numbers of each individual amino acid would vary from protein to protein.

The net result is that while the total number of possible protein

molecules remains finite in a mathematical sense, it is to all practical purposes infinite.

There may have been tens of millions of different species of living things on Earth during the course of its history, and each species would have to have distinctively different protein molecules. There would be room for that.

Each individual organism may not be quite like any other organism of that species and, therefore, must have somewhat different proteins. There's room for that.

It may be that only one particular protein arrangement out of a billion, or out of a trillion, has any chance of having biological significance. That one out of a billion, or out of a trillion, is still enough for everything on Earth.

In fact, if there are protein-based forms of life on a trillion different worlds, the chance of any of them duplicating what exists on Earth or on any other world is virtually zero. There is room in the protein molecule for everything on every habitable world.

Astounding, isn't it? I've thought about this for nearly forty years and I've never stopped being astounded.

Last month, we discussed enzymes, and the question arose as to what, exactly, the chemical nature of enzymes might be. It is easy to suppose that they are proteins for there are many different enzymes in the human body, and many other enzymes in every species of living thing, all of them possessing distinctive properties. It is quite possible for different species of organisms to have enzymes of slightly different properties even when they perform the same basic functions and, as the enormous range of protein structural possibilities became clear, it was natural to assume that enzymes were proteins.

However, an assumption is not evidence, and what chemists wanted was to purify enzymes — to obtain solutions that showed enzymatic properties, but from which all non-enzyme material had been eliminated. They might then show that the material in solution gave a positive test for protein — or did not.

The person who tackled this problem was a German chemist, Richard Willstätter (1872-1942). He was a real heavyweight and was one of the outstanding chemists of his time. He had done important work on the structures of chlorophyll and other plant pigments and had received the 1915 Nobel Prize in chemistry as a result.

In the early 1920s, he began to work on the structure of enzymes. He worked with an enzyme called "invertase," which split table sugar

(sucrose) into two simpler components, glucose and fructose. Whereas sucrose twisted the plane of polarized light in one direction, the mixture of glucose and fructose twisted it in the opposite direction. It was from this inversion of the twist that the enzyme got its name.

Willstätter carefully purified the enzyme, getting rid of extraneous materials. At every step he tested each fraction for invertase activity, keeping the particular one that showed activity and purifying it further.

In the end, he had a clear solution that was quite active in splitting sucrose into its components, but that did not yield a positive result for even the most delicate known test for proteins. Furthermore, there was no sign of any amino acids in the solution, either free or in the form of peptide chains.

The conclusion was obvious. Willstätter stated firmly that enzymes were not proteins but had to be small molecules of unknown composition, molecules that had thus far not been studied systematically. No one doubted his conclusion, and the matter seemed to be settled in a negative sense, at least. Chemists thought they knew what enzymes were not.

Yet there was a major flaw in Willstätter's reasoning. Enzymes were, apparently, catalysts, bringing about reactions without themselves being directly involved. It was known that catalysts were sometimes effective in very small concentrations. What, then, if enzymes were particularly efficient as catalysts and did their work in such tiny concentrations that, although they were proteins, there was never enough protein present to react to any of the tests in a visible manner?

Naturally, it was not enough to say that was possible. It had to be proved by hard and fast evidence.

In 1927, Willstätter visited Cornell University to lecture on his notions on enzyme structure. What he didn't realize was that, in the audience, was a biochemist who had already proven him to be wrong.

That biochemist was James Batcheller Sumner (1887-1955). When he was still a teenager, he suffered a hunting accident and had to have his left arm amputated. Since he was left-handed, he had to train himself to use his right hand. With ferocious dedication, he went on to college and graduate school, and finally joined the faculty at Cornell University Medical College.

What Sumner decided was that, in purifying an enzyme, he would not seek to obtain a water-solution that would contain too little enzyme to test for. He would subject his fractions to the kind of chemical procedures that would produce cry-

stals. If the enzyme, whatever it might be, could be obtained as crystals, some of those crystals could be dissolved in a minimum quantity of water, and the result might be a solution that could yield positive results for protein (or not).

He studied an enzyme called "urease," which split urea into the simpler molecules of ammonia and carbon dioxide. Since jackbeans were particularly rich in urease (or, at least, showed high levels of urease activity), he ground them up and began the process of extraction and fractionation.

In 1926, he obtained small crystals which, when dissolved in water, showed tremendous urease activity and responded positively to tests for protein. Attempts to purify the crystals further could not separate the protein from the activity, and Sumner finally decided that urease was a protein and that, very likely, other enzymes were proteins as well.

Sumner published his paper on the subject, but almost no one paid attention. Willstätter's prestige was enormously higher than that of the unknown Sumner, and it was easy to argue that some small enzyme compound just happened to tie itself tightly to an inert protein carrier.

Others, however, threw themselves into the task of crystallizing enzymes, and the American biochemist John Howard Northrop (1891-1987) crystallized "pepsin" in 1930, "trypsin" in 1932, and "chymotrypsin" in 1935. These were three different digestive enzymes, and Northrop showed that each one was a protein.

The result was that in 1946, Northrop and Sumner won shares in the Nobel Prize in chemistry. The matter was settled. Enzymes have been crystallized in numerous cases and all, with no exceptions, have been proteins. (It is possible that non-proteins may have catalytic properties. This may well be true of ribonucleic acid, for instance, but it is nowhere near as efficient as protein catalysts.)

But how does an enzyme work? Emil Fischer, who was the first to work out the structure of the peptide chain, was also the first to suggest the existence of a lock-and-key mechanism.

A given enzyme has a particular surface structure, and it might well be that a portion of the surface, both in bulk and electric charge, is such that some molecule just happens to fit that surface. Its surface zigs where the enzyme's zags; it has a negative charge where the enzyme has a positive charge; and so on.

Such a well-fitted molecule, if it strikes the enzyme surface through

the random thermal motions that all molecules undergo, sticks to the surface tightly. Other molecules that don't fit the surface merely strike and bounce off.

The molecule that fits the surface probably doesn't fit exactly. There is a slight strain, a slight stretch imposed on the bonds that connect two of the atoms. The result is that the bond can add on the component atoms of water, let us say, and break apart. This happens far, far more readily than if the molecule were not on the enzyme surface but were just floating around the cellular contents by itself. Thus, sucrose can remain in solution indefinitely without splitting up into a glucose and fructose, but when there is a bit of invertase present, then every time a sucrose molecule fits onto the invertase surface, it breaks in two almost at once.

Once the break takes place, the individual glucose and fructose molecules don't fit the surface as well and they come away. There is then room for another sucrose molecule to strike and so on.

Enzymes can also cause two molecules to combine into a larger one. Small molecule A fits the surface just here, and small molecule B fits the surface very near by. The two are oriented in such a way that a bond can easily form between two atoms, producing a larger molecule that no longer fits quite so well, and leaves the surface.

This view of the matter explains a great deal. Each individual enzyme molecule can bring about thousands, or perhaps even millions, of changes among the small molecules that surround them, and do so in a very short time. This means that a particular enzyme need be present only in traces — which was what Willstätter stumbled over.

Some enzymes only work when a particular metallic atom is incorporated into their structure — copper, zinc, molybdenum, and so on. Such atoms are necessary in the diet, but only in traces. They are therefore called trace minerals. In some cases, rare organic groupings must be present, and these are the vitamins which must therefore exist in the diet.

In reverse, there are substances that interfere with the working of enzymes. In putting the relatively few enzyme molecules in the body out of action, changes of great importance are prevented from taking place, and life may become impossible. That is why some poisons kill quickly in even tiny doses.

You can also see the importance, now, of the infinite complexity of the protein molecule. It is easily possible to find a protein surface that just fits any given molecule.

For that reason, it is possible for a human being to have a thousand different enzymes, each capable of bringing about a particular chemical reaction with great rapidity.

Since the cells have devices that can activate and inactivate enzymes, different chemical changes can be hastened or slowed and, in a healthy body, all the changes take place smoothly and appropriately.

Naturally, different species have enzymes of slightly different nature that produce changes of different types in different balance so that a giraffe ovum becomes a giraffe and an elephant ovum becomes an elephant and never vice versa.

And we can be sure that extraterrestrial creatures will be nothing at all like any creature of Earth.

There is a certain tendency to make enzymes (and catalysts, generally) into mysterious objects. It seems mystical to say that an enzyme, or any catalyst, can bring about a quick chemical change without itself being changed in the process.

The lock-and-key mechanism should remove all of this mystery and demonstrate the process to be perfectly natural and above-board, but we don't have to stay at the molecular level to explain it. We can give a very precise example of a catalyst and the manner of its working in everyday terms.

Suppose, for instance, you want to write a note. You have only a piece of thin, flimsy paper and a pen and you are standing on a pebbly beach. You can try to write the note while holding the paper in your hand but it will crumple and tear. You can put it down on the pebbles and try to write, but it will crumple and tear even worse. Neither your hand nor the pebbles offer a suitable surface.

If, however, you have a nice, smooth piece of wood, you can place the paper on the wood and write the note neatly and quickly. You can write hundreds of notes if you wish and, in the process, the piece of wood does not change, nor does it participate actively in the writing. It merely offers a convenient surface — and that is what an enzyme, or a catalyst, generally, does.

No mystery.

SCIENCE

ISAAC ASIMOV

SOMETHING FOR NOTHING

LIKE ALL literate kids, I read the tale of Aladdin and his Lamp when I was quite young, and like every kid who did so, I wanted that lamp. I had visions of finding an old lamp in a garbage can (though I had no idea of what such a lamp was supposed to look like), and rubbing it, and promptly encountering an eager genie who would want to fulfill my every wish.

The only catch was that I didn't know what to wish for. Aladdin had wished for a castle, and dancing girls, and slaves carrying trays of gems, and a feast on golden dishes. I had a feeling, however, that if I showed up with any of these things — especially dancing girls — in the noble borough of Brooklyn, it would cause comment.

So my nine-year-old self decided that the best thing would be to ask for money. Gold coins would be the most thrilling, but, on the whole, I thought I would be better off with American bills. Once I had those, I would at once turn them over to my father. (It never occurred to me that I might keep the money for myself.)

How much money? To my young imagination, a thousand dollars was virtually infinite, so I thought of how pleasant it would be to have a thick sheaf of ones, fives, tens and twenties, and hand them to my father and say, "Here's a thousand dollars, Pappa."

But then I had a follow-up vision. My father would turn white, his eyes would grow large and round, and, refusing to touch the bills, he would thunder, "Where did you get that money, Isaac?"

It would be no use explaining. He would be convinced that I had somehow learned how to rob a bank at the age of nine, and he would have called the police and turned me in. That's how Talmudic patriarchs managed things.

After all, Abraham had been told

by God to drag off his son to the wilderness and sacrifice him, and Abraham promptly set out to obey. And his son, who was saved at the last minute, was also named Isaac.

I felt I couldn't take the chance, and I stopped looking for Aladdin's lamp in the garbage cans I passed.

But then I became an adult and, little by little, accumulated Aladdin's lamp, or at least the nearest thing to Aladdin's lamp that can exist in reality. It's called "money."

I sit about these days trying to plan my estate so that when I pass on to that great word-processor in the sky, the government, in collecting its share, will leave a few pennies for my wife and children. It's a very difficult problem.

My dear wife, Janet, who loves me more than she loves herself for some reason no one can possibly define, watched me suffer and said recently, "Why do you worry about survivors? Why don't you spend some of your money on yourself? You have food, shelter, clothing, a nice apartment, work-material — but surely there is some useless luxury you want, some decadent possession, some silly thing. Whatever it is, you can afford it, so why not go for it?"

"Hey," I said, "what an exciting idea." And, after sixty years, I returned to the task of figuring out what I wanted the genie to do for me. And after a lot of pondering, I came up with the same old answer.

"Janet," I said, "the trouble is that there's nothing I want."

"You're hopeless," she said — a conclusion she comes to anyway, two or three times a week.

The world in general, however, does want something. If possible, it wants it for nothing, to have it showered on it by a genie.

All through history there has been an impatience with the bonds of natural law and a feeling one ought to seek for help outside those bonds, to fairy godmothers, to angels, to gods and demons.

Millions of people in America today pray earnestly and periodically, in the hope that as a result of their ardent pleas, God will set aside the laws of nature for their convenience.

If, however, we confine ourselves to observing nature, then we come to the opposite conclusion. Far from getting something for nothing, we are getting nothing for something. Everything that lives eventually dies. Many things, including corpses, rot with time. Motions slow and eventually stop, whether it is the motion of a living thing or of an inanimate object.

It was observations such as these that made the early philosophers (and their successors right down to

the 1600's) feel that Earth was a place of corruption and decay, of continuous disintegration. It was amazing that it had not yet entirely decayed, but European philosophers, at least, expected that the day of judgement would not be long delayed, and universal decay might herald that day.

The heavenly bodies, however, clearly did not change or decay but kept rolling about the sky forever. Their fires did not go out as Earthly fires did. Their motion did not slow up. It seemed clear to Aristotle (384-322 B.C.) that the Earth and the heavens were made up of fundamentally different materials and followed altogether different laws of nature.

It was not till the 1600's that scientists were able to show that the same laws of nature governed the Earth and all the other objects of the Universe. It was not till then that they could show that objects of Earth, in some ways, did not change or decay. There were aspects of matter that were as eternal and changeless on Earth as they appeared to be in the sky.

(In the 1800's, to be sure, scientists found that everything did indeed decay and disintegrate, not only on Earth but in every part of the Universe. This decay, however, was after a fashion that was much more subtle than that which had been worked out by the ancients.)

Let's start with billiard balls. Billiards had been played, I am sure, long before the laws of motion were worked out by Isaac Newton (1642-1727) in 1687. Billiards is played today, and with enormous expertise, by people who know nothing about the laws of motion as formal statements. However, they know how billiard balls move, what happens when they hit each other or the rim of the billiard table.

When a billiard ball hits the rim of the table, it rebounds, moving in another direction (depending on its angle of impact) with the same speed it had at the start. (Actually, some speed is lost because there is friction between the rolling ball, the table's surface, and the table's rim, but that loss is very small and we can ignore it.) Similarly, if two billiard balls, moving at equal speeds, strike each other head-on in mid-table, they rebound and move away from each other at the same speed with which they had moved toward each other.

It would seem from considerations like this that, if we ignore friction, velocity is not lost in the course of the movements of billiard balls. We might say the velocity is conserved — except that it isn't. The only reason it seems to exist in the conditions I have been discuss-

ing is that all the billiard balls are of equal mass.

Suppose, though, that we imagine two billiard balls, one of which is somewhat more massive than the other, speeding toward each other at equal speeds. Both rebound, but the lighter one rebounds faster than the more massive one, and if the speeds of rebound are totaled, they turn out to be not quite the same as the total speeds of impact. Speed has not been conserved.

The English mathematician John Wallis (1616-1703) pointed out in 1668 that the true measure of motion was not speed alone, or, more accurately, "velocity" (v), but was mass multiplied by velocity (mv). This product he called movement or, in Latin, "momentum."

It turned out, on measurement, that momentum is conserved. No matter how billiard balls (or anything else) strike and rebound, the amounts of momentum after the rebounding is exactly the same as before (once again, ignoring friction).

It's not as simple as it sounds, however. Billiard balls are just about perfectly elastic and lose nothing in the act of impact and rebound. Imagine, though, you have two billiard balls racing toward each other and, at the moment of impact, they turn into clay. Now you have a totally inelastic impact. The clay deforms and sticks together and neither billiard ball rebounds. Indeed, they remain stuck together and entirely motionless. Both balls had momentum as they sped toward each other, and now that they are motionless, the momentum is gone. Since momentum ought to be conserved, what happened to it?

Velocity is a "vector quantity." That means, it has direction as well as speed. In fact, "speed" is merely the rate of movement in any direction. As soon as we specify a direction as well, it becomes "velocity."

Since momentum is mass times velocity, momentum is also a vector quantity, and direction of movement must be taken into account. It is customary, therefore, to measure momentum in a particular direction as a positive quantity (+mv) and momentum in the opposite direction as a negative quantity (-mv).

If two objects of equal mass, moving at equal speed, meet each other head-on, and suffer an inelastic collision which leaves them stuck together and motionless, we have demonstrated that +mv added to -mv equals zero, and momentum is indeed conserved.

If one object moves a little faster than the other before impact, then the two stick together and move in the direction of the faster motion

with just enough speed to conserve total momentum. If the two objects are partly elastic and rebound, but with less speed than before the impact, the total momentum is still unchanged.

If two objects collide at an angle, they rebound at an angle, but if the momentum of each object, before and after collision, is measured with methods called "vector analysis" so that each object has its motion converted into a positive and negative component, we find that momentum is conserved.

In fact, imagine an object sitting quietly and at rest, with a momentum of zero. Suddenly, it explodes and its fragments fly in all directions. Each fragment has a momentum that is not zero, but if all the momenta are added vectorially, it turns out that the total remains zero.

It is not the momentum of each component of a system that is conserved, but the total momentum of the entire system.

When we consider the conservation of any property, we must be careful to consider a "closed system"; one where some of that property does not leak in from outside or leak out to the outside, either.

If we imagine billiard balls moving about on an infinite surface, impacting and rebounding, then that surface is a closed system, always ignoring the imperfections of friction.

A billiard table is, however, a small object with a rim. Imagine a billiard ball striking the rim of a table head-on and rebounding in its tracks, moving away along the same line and at the same speed with which it impacted. In this case, +mv has become -mv, and it would seem that momentum has not been conserved.

Not so, for the billiard table is itself part of the system, and when the billiard ball strikes the rim and rebounds, the table also rebounds in the opposite direction. Moreover, the billiard table is attached (by frictional forces, if by nothing else) to the Earth, so it is the entire planet that rebounds.

Since the Earth has a mass something like a thousand trillion trillion times that of a billiard ball, the planet recoils at a velocity only a thousandth of a trillionth of a trillionth that of the billiard ball — a velocity entirely immeasureable, but it's there. This is something people don't think of ordinarily. You don't think that the Earth is responding to the motion of billiard balls.

Probably the first thought that occurs to anyone who does hear of this for the first time (it certainly occurred to me) is that if enough

billiard balls are bounced in the same direction, then eventually Earth's motion through space will be measureably affected.

The billiard ball strikes the edge of the table and rebounds. After it rebounds, it is stopped by your hand, let us say. That alters its momentum at once, and the momentum of the Earth is also altered. A billiard ball can undergo all kinds of motions and impacts and rebounds, with the Earth following faithfully, but eventually, the billiard ball, which was originally stationary, is stationary again and has regained its initial momentum of zero, and so does the Earth.

This also applies to the motion of cannonballs, the explosion of nuclear bombs, the falling of avalanches, the coming and going of ice-caps and so on. The momentum of the Earth as a whole is not, and cannot in the long run, be changed by alterations of any kind within the Earth — so its motion moves on with majestic constancy, barring always impacts and influences from outside the planet.

Wallis's law of conservation of momentum was the first of the great conservation laws to be established, and, after almost three and a half centuries of intense study, no exception to it has ever been clearly noted.

These conservation laws are, of course, merely generalizations that have been observed to exist. There is always the possibility that under certain unexpected circumstances they may be broken. Such circumstances have never been observed for the law of conservation of momentum, however, and you are not going to find any scientist who will risk any money on the possibility that the law of conservation of momentum will ever be broken.

There is a similar conservation law for objects that are turning rather than moving in a straight line. Turning objects demonstrate "the law of conservation of angular momentum."

Angular momentum is also a vector quantity and can exist in two opposite directions, clockwise and counterclockwise. Two objects, turning in opposite directions, might mesh and the turning will then stop altogether. Again, an object with zero angular momentum, if exploded, may produce fragments each of which is turning, but all the angular moments, if added together, will then come to zero.

Ordinary momentum and angular momentum are so similar in some ways that it is natural to wonder if it is possible to turn one into the other. Not really. They are two independent phenomena and exist separately.

It may seem to you that that's not so. After all, if a horse pulls a wagon and gives it momentum, the wheels begin to turn so that the pull also creates angular momentum. Again, the rapid turning of the engine in an automobile produces the turning of wheels which, in turn, causes the car to move in a straight line at a great speed.

This, however, is entirely the result of frictional forces. The horse, in pulling the wagon, pushes against the Earth, which develops an equal momentum in the direction opposite to the one the horse creates. And when the wheels turn, it means that the Earth's angular momentum is equivalently changed in the opposite direction.

Things would be entirely different if friction were not involved. Imagine a car resting on a surface of perfectly smooth ice. You can start the engine and the wheels can be made to whirl, but the car won't budge from its place — not without friction. Nor can the horse make the wheels of the wagon turn as his hooves scrape uselessly against the ice.

Is it possible, then, to initiate motion in the absence of all friction?

Of course it is. An object hanging in outer space, if it explodes, will have portions of itself moving in all directions, and turning in all directions, too. The total momentum after explosion, however, is the same as it was before the explosion; and that is independently true of angular momentum as well.

But suppose you don't want to fly in all directions. Suppose you have a vehicle which you want to move in some specific direction through space, and you want to do it from a standing start. In that case, Newton pointed out that the only way of doing that was to arrange to make a portion of the vehicle move in one direction, so that the remainder of the vehicle would move in the opposite (desired) direction. Only so could the vehicle conserve momentum.

Imagine that you are on a large sled, resting on a sheet of frictionless ice and that with you in the sled is a pile of bricks. If you throw a brick in the direction opposite to that in which you want to go, the sled will at once move in the direction you do want to go. In the absence of friction, it will maintain that speed undiminished. If you throw additional bricks after the first in the same direction, the sled will pick up speed with each brick, and will finally be barrelling along.

The same thing works in space. Fuels are burned within the ship to create hot gases, which, under their own pressure, jet out in one direction so that the space ship is forced to move in the other.

When the American physicist Robert Hutchings Goddard (1882-1945) was trying to send small liquid-fueled rockets high into the atmosphere, with the ultimate intention of working out a way to reach the Moon, he was roundly denounced in an editorial in *The New York Times.* This editorial, which became famous, informed Goddard how foolish he was not to know what every high-school boy knows, that you can't have motion unless you have something to push against.

The *Times* editorialist understood the importance of frictional forces, but, alas, he obviously knew nothing about the law of conservation of momentum or (its equivalent), Newton's third law of motion.

The rocket principle—this business of sending part of a system in one direction so that the rest may go in the other—seems extraordinarily wasteful. A spaceship must carry vast amounts of fuel to make progress, and it is only natural to look for some other way of doing it.

What if you could somehow turn angular momentum into ordinary momentum? What if you could make a wheel turn on board a spaceship and change that turning motion into the ship's straight motion. It might be much more efficient to keep the wheel turning and the ship moving, than to expend tons of fuel jetting out of the ship.

In the 1960's, a gentleman named Dean (I don't know his full name) claimed to have invented a device in which angular momentum was converted, at least in part, to ordinary momentum. If he set his wheeled device to turning, it would exert an upward momentum if properly oriented. He could prove this by placing it on a scale. The weight of the device would decrease when the wheel turned because it had a tendency to lift upward. In a sense, this would have the effect of anti-gravity, and it might lift spaceships up and into outer space more efficiently than the rocket principle would.

The interesting part of this to science fiction people is that John W. Campbell, Jr., the great editor of *Analog,* was a sucker for all kinds of fringe aspects of science, and he fell for this "Dean Drive" all the way. He was sure it worked and pushed it in the magazine all he could.

In scientific matters, I am a hard-line conservative, and to me the possibility of converting angular momentum into ordinary momentum is exactly as large as the possibility of finding Aladdin's lamp in a garbage can. I refused to believe that the Dean Drive had any value whatever, and in this I was joined

by a number of other science fiction writers who had had scientific training.

None of this stopped Campbell, who was sure that scientists tended to get hardening of the intellectual arteries, so that they were forced to turn blindly away from anything that offended their ingrained prejudices.

Of course, John wasn't entirely wrong there. Scientists have been known, on occasion, to refuse to accept something worthwhile, despite all the evidence, simply because it didn't fit in with their beliefs.

However, beware fallacies. Just because scientists are sometimes blinded by prejudice to the new and useful, does not mean that any fringe belief must be true simply because scientists deny that it is. In almost all cases, when reputable scientists dismiss something as a violation of the laws of nature, it is indeed a violation and will not endure.

And the fact is that absolutely nothing has come of the Dean Drive.

Now we come to the problem of friction and momentum. Imagine a billiard ball on a table surface that is hit with a cue so very, very gently, that it hardly moves. Nevertheless, you have imparted a tiny momentum to it. The billiard ball may then move only a few inches, slowing and stopping because of frictional forces. What has happened to its momentum?

A proper answer to that question only came after the nature of heat was understood. Through the 1700's, heat was thought of as a subtle fluid (rather as we now think of the electric current). Different objects contained different quantities of the fluid, and it could travel from here to here just as any other fluid would.

In 1798, however, Benjamin Thompson, Count Rumford (1753-1814), a Tory exile from the United States, was boring cannon in the service of the Elector of Bavaria. He noted that great quantities of heat were formed in the process. Neither the cannon being bored nor the boring instrument used was at more than room temperature to begin with, and yet the heat developed by the act of boring was sufficient to bring water to a boil after a time, and the longer the boring continued, the more water was boiled.

It was clear to Rumford that the act of boring created heat, and he suggested that the friction of the borer against the metal of the cannon put tiny parts of both into rapid motion, and that heat was an expression of this motion.

At the time, Rumford's point

was ignored, but the passing of a few years made a change. Within a decade of Rumford's observation, the British chemist John Dalton (1766-1844) had brought out a convincing atomic theory, and chemists quickly began to think of matter as composed of tiny atoms.

It was these atoms, then, that were set into motion by friction, and it was that atomic motion that could be interpreted as heat.

In the 1840s, an English scientist, James Prescott Joule (1818-1889), studied heat carefully (something I will take up next month), and Rumford's suggestion began to appear to make more and more sense.

In the 1860's, A British physicist, James Clerk Maxwell (1831-1879), and an Austrian physicist, Ludwig Boltzmann (1844-1906), independently worked out the mathematics of atomic motion within matter, showing that the notion of random motion of the atoms as an expression of heat (the "kinetic theory") was entirely justifiable.

This makes the frictional effect on momentum clear. When an object moves along a surface, there is never zero friction. There are always little unevennesses in the object and in the surface along which it moves. These catch at each other and it takes effort to overcome them. Every such catch cuts down the speed of the moving object and therefore decreases its momentum.

This happens very rapidly if a brick is sliding over a rough, wooden floor. It happens very slowly if a smooth metal object is sliding across ice. Eventually, though, if you wait long enough, velocity and momentum decline to zero.

But the momentum has not disappeared. It has been transferred to the atoms making up the surface of the moving body and the surface along which it moves.

Fundamental as the laws of conservation of translational momentum and angular momentum are, there is another which most people consider even more fundamental — perhaps the most fundamental of all the laws of nature. That is the law of conservation of energy, which, among other things, outlaws Aladdin's lamp completely, and I will turn to that next month.

SCIENCE

ISAAC ASIMOV

THE UNCHANGING AMOUNT

MY FAMILY and friends tend to use me as a walking encyclopedia. This is flattering, but can easily be a source of embarrassment to me when it turns out that I do not know everything after all.

My beautiful daughter, Robyn, had learned of this know-it-all reputation by the time she was ten. I was away on a trip, and my first wife, Gertrude, and her visiting brother, John, got into a controversy that could not be resolved. They therefore sent Robyn upstairs to get the appropriate volume of the Encyclopedia Britannica.

Robyn was most reluctant to take the trouble, and halfway up the stairs, she shouted, "If Daddy were here, you could just ask him."

My friend the science fiction writer Lin Carter called me once and said, "Isaac, who said, 'Liberty! Liberty! What crimes are committed in thy name!'"

I answered, without hesitation, "Madame Jeanne Roland, on her way to the guillotine in 1793." That seemed to astonish him.

However, I sometimes fail. A year or so ago, my friend the science fiction writer L. Sprague de Camp, called me from his home in Texas. "Isaac," he said, "I need to know the wavelengths of the ultrasonic waves emitted by bats in flight. I can't find the information, but I'm sure you would know it off-hand."

"I'm sorry, Sprague," I said, "I do not know it off-hand, but I will go through my reference library and see if I can find it. If I do, I will call you back."

I then began to ransack my library and found, rather to my astonishment, that all the books I was sure would have the information did not. Even the Encyclopedia Britannica failed me. I was about to give up, when I thought I'd try the Encyclopedia Americana, and there, in an article on "Sound," was the information I wanted on bat

squeaks. I called Sprague and read it off to him.

"Thanks, Isaac," he said, "that's just what I wanted."

After he hung up, I began to brood about the information having been presented so clearly and concisely. I went back to the start of the article and began to read. It was very well-written and that displeased me. I don't like to see other science writers doing a good job. So I looked at the end of the article to see what scoundrel had written the piece. And there, in bold print, was the name — Isaac Asimov. I had forgotten that I had written an article on "Sound" for the Encyclopedia Americana.

Things like that, however, always encourage me to continue my endless series for F & SF, and so here we go again.

Last month, I spoke about the conservation of momentum, where momentum is the product of mass and velocity (mv). Most scientists, including the Englishman Isaac Newton (1642-1727) and the Frenchman Rene Descartes (1596-1650) took this as a measure of motion.

This was disputed by the German scientist Gottfried Wilhelm Leibniz (1646-1716). Leibniz was one of the greatest scientists who ever lived, but he had the incredible misfortune to be an almost exact contemporary of the still-greater Newton, and to have engaged in controversies with him. That led to the underrating of Leibniz, particularly in the English-speaking countries.

Leibniz advanced reasons for supposing that the measure of motion was related to the mass multiplied by the square of the velocity (mv^2), and in this he was more nearly right than Newton was.

Leibniz was also the first to point out the importance of a quantity that represented a force moving a mass over a distance against a resistance. This product of force and distance (fd) was called a variety of names but, in 1829, the French physicist Gustave Gaspard de Coriolis (1792-1843) was the first to call it "work." He also pointed out that it was more convenient to speak, not of mv^2, but of "$\frac{1}{2}mv^2$."

Work, in the scientific sense, is not quite the same as work in the ordinary sense. Thus, if I were to lift a heavy suitcase a few inches off the ground, I would be doing an amount of work equal to the mass of the suitcase, multiplied by the distance it was raised against the pull of gravity.

If, however, I then held the suitcase in place at the height to which I had lifted it, I would gradually grow very tired, and it would seem like "hard work" to me. But it isn't.

As long as the suitcase doesn't move against the pull of gravity, no work, in the scientific sense, is being done. What you feel as "hard work" is the result of the molecules of the muscles being forced to retain their contracted state against the natural tendency to relax. You can see that if you shove a piece of wood under the suitcase and let the suitcase rest on it. The wood would hold up the suitcase as your arms did, but it would never grow tired and it would not do any work. (I wish, for this reason, that work in the scientific sense had been called something else, but it's too late now.)

Anything capable of doing work, such as your muscles, contains "energy." Energy is from Greek words meaning "work within." The word was first used in 1807 by the British physicist Thomas Young (1773-1829).

The expression $\frac{1}{2}mv^2$ represents "kinetic energy," where "kinetic" is from a Greek word for "motion." It is the energy possessed by a moving object. A motionless baseball will do no work. A thrown baseball can easily break a window. A baseball thrown by a fast-ball pitcher can kill a man if it hits him on the skull. Things that are still more massive and move still more rapidly can do much more work of a damaging kind. Think of a cannonball.

* * *

But where does the kinetic energy come from? We make a ball move by throwing it, but trying to deal with what goes on in the living body introduces complications we don't need.

Let's make it simple. Imagine a ball being held motionless at some height. Because it has no motion, it has no kinetic energy. If, however, it is released, it promptly responds to the pull of gravity and begins to fall, so that it gains kinetic energy. Because it falls more and more rapidly with time (as was first pointed out by the Italian scientist Galileo [1564-1642] in the 1590s), it gains more and more kinetic energy as it falls. How much kinetic energy it gains by the time it strikes the ground depends on how high the ball was suspended in the first place.

Obviously, there is not only an energy of motion but an energy of position in the gravitational field. This was first pointed out clearly, in 1803, by a French engineer, Lazar Nicolas Marguerite Carnot (1753-1823). (Carnot is better known as an honest and efficient French Revolutionary, who built up the French army after the first period of chaos of the Revolution, and thus laid the groundwork for Napoleon's later victories.)

In 1853, this energy of position was first called "potential energy"

by the British engineer William John Macquorn Rankine (1820-1872) for obvious reasons.

The potential energy we generally speak of is that within a gravitational field, but there are phenomena other than gravitation that will cause motion. Electricity will do it, for instance, and if an object is held steady against the tendency of an electric field to make it move, that object then has potential energy within an electric field, and so on.

However, the matter of kinetic energy and potential energy was first recognized with respect to the ubiquitous gravitational field we are all immersed in, and we'll stick to that. The two forms of energy, taken together, can be termed "mechanical energy."

It is the common experience of humanity that if an object is hurtled straight up into the air, its speed steadily decreases as it mounts higher. In short, its kinetic energy starts at some high level when it is on the ground and when its potential energy is zero. As it rises, the kinetic energy decreases, but the potential energy increases. Finally, it reaches a maximum point at which it stops rising. Its kinetic energy is then zero and its potential energy is at the highest. After that, the ball begins to fall, losing potential energy and gaining kinetic energy.

Since the ball returns to the ground with the same speed that it left, that gave rise to the notion of the "conservation of mechanical energy" — that the sum of kinetic and potential energy always remains the same in a closed system.

The only trouble is that it doesn't. If you let a ball bounce, it will reach a slightly smaller height with each bounce and will finally dribble to a halt. Both potential energy and kinetic energy would decline to zero. Where did they go? They either had to go somewhere or else the law of conservation of mechanical energy simply isn't true.

Or suppose you roll a ball across a rough surface. It gradually slows, without ever leaving the surface. The kinetic energy disappears, but no potential energy appears to compensate that loss. Again, where did the kinetic energy go?

It turned out with time that other forces that could induce motion and do work, other forms of energy, could not be conserved either. They all dribbled down to nothing with time.

It was rather disappointing that energy would not be conserved, for conservation is a neat arrangement and scientists like the Universe to be neat.

Let us pass on to heat, then.

Heat flows spontaneously from a hotter object to a cooler one, much in the way that water flows, spontaneously, from a higher position to a lower. It was only natural, then, to think of heat as a kind of fluid. The French chemist Antoine Laurent Lavoisier (1743-1794) wrote a chemistry book in 1794 in which he listed the materials he considered "elements" (substances that could not be broken down into still simpler substances). Among these elements, he listed light and heat. Heat he considered to be a fluid which he called "caloric" from a Latin word for "heat."

The fluid theory made it possible to deal with many manifestations of heat without trouble, but even so, various scientists (even Lavoisier) speculated that heat might be a form of motion. These were only speculations, however, and what one needs in science is experimental evidence. The first to supply this was Benjamin Thompson (1753-1814), better known as Count Rumford.

Thompson was an American, but during the Revolutionary war, he was a Tory and spied for the British. As a result, he thought it better to leave with the British when they left Boston. After the United States gained its independence, Thompson went to Europe and remained there. He eventually entered the service of Elector Karl Theodor of Bavaria, and it was from him that he got his title.

In 1798, Rumford was supervising the boring of cannon, and he noticed that the blocks of metal grew hot as blazes as the boring tool gouged them out. They had to be cooled consistently with water.

The orthodox explanation for this was that caloric was being loosened from the metal as the metal was broken down into shavings by the boring device. However, the heating continued as long as the boring went on, and enough caloric was removed from the metal being bored to have melted that metal if it were poured back in. In other words, more caloric was being removed from the metal than could possibly have been contained in it to begin with.

What's more, caloric could not be produced by the break-up of the metal. Rumford made use of a boring instrument that was so dull it did not shave off any pieces of metal. Nevertheless, if he ground that dull boring device into the metal, more heat, not less, was produced than if he had used a sharp one.

Rumford's conclusion was that the mechanical motion of the borer was being converted to heat and that heat was therefore a form of motion, motion of tiny fragments

of the metal. This result was obtained not by speculation but by experiment. Rumford tried to calculate how much heat was produced by a given quantity of mechanical energy and was the first to set a figure for what we now call "the mechanical equivalent of heat." The figure he obtained was far too high, but it was a start.

Another experiment, conducted not long after by the British chemist Humphry Davy (1778-1829), led to the same conclusion. Davy set up a system in which ice was rubbed mechanically at temperatures that were maintined a degree below the freezing point. There was insufficient caloric in the whole system, according to the orthodox view, to melt the ice, and yet it melted. Davy decided that the mechanical motion was converted to heat.

In 1803, the British chemist John Dalton (1766-1844) advanced the atomic theory, and scientists began to believe that all matter was composed of tiny atoms and molecules. It was the motion or vibration of these that might represent heat.

In the 1860s, the British physicist James Clerk Maxwell (1831-1879) and, independently, the Austrian physicist Ludwig Edward Boltzmann (1844-1906), in the 1870s, developed a mathematical treatment that firmly established the motion theory of heat. Heat was the motion of atoms and molecules, and the more rapid the average motion the greater the intensity of heat (that is, the "temperature").

Once the notion of heat as a form of motion began to take hold, there would naturally be those who felt that the conservation of energy would work if only heat were taken into account. If a moving object came to rest, it must be because the object's motion was converted into the motion of atoms and molecules, that is, into heat.

The first to point this out was a German physicist, Julius Robert Mayer (1814-1878). In 1842, he presented a figure for the mechanical equivalent of heat, based on an experiment in which a horse powered a mechanism that stirred paper pulp in a cauldron. He compared the work done by the horse with the temperature rise in the pulps, and his figure was better than that of Rumford.

Mayer, in reporting on this experiment, expressed his belief that, counting heat, energy was conserved; that the law of conservation of energy held even for living systems; and that solar energy was the ultimate source of all energy on Earth, both living and non-living.

Unfortunately, Mayer was a physician and not a University

academic, and his work was totally disregarded. Even when the law of conservation of energy was accepted a few years later, Mayer received no credit for being first. In fact, Mayer's life was a tissue of incredible misfortunes. In 1848, two of his children died, and his brother was involved in revolutionary activities. Mayer tried to commit suicide in 1849 by jumping from a third-story window, but merely injured his legs permanently. In 1851, he was taken to a mental institution for a period of time and there he was cruelly treated.

After release, he lived in such obscurity that when the German chemist Justus von Leibig (1803-1873) lectured, with praise, on Mayer's work, he assumed that Mayer was dead. That, however, brought Mayer appreciation at last, and he received the Copley medal in 1871.

Next came the work of the British physicist James Prescott Joule (1818-1889). He had to run his father's brewery, which cut into his time, but he was a virtual fanatic on the measurement of heat. In his teens, he was already publishing papers in which he was measuring heat in connection with electric motors.

He went on to devote years to measuring the heat produced by every kind of work he could think of. He churned water and mercury with paddles. He passed water through small holes to heat it by friction. He expanded and contracted gases. Even on his honeymoon, he took time out to devise a special thermometer to measure the temperature of the water at the top and bottom of a scenic waterfall his wife and he were to visit. After all, kinetic energy of the falling water should be converted to heat.

In all those cases, he calculated the amount of work that had entered the system and the amount of heat that came out, and he found that the same amount of work, of whatever kind, always produced the same amount of heat. He calculated, in 1843, that 41,800,000 ergs of work produced one calorie of heat.

Joule was not the first to calculate the mechanical equivalent of heat. Rumford and Mayer had beaten him to the punch, but Joule's was the first accurate value, and the first to be backed by a large variety of different experiments. In his honor, a unit of work equal to 10,000,000 ergs is now called the "joule," so that 4.18 joules of work equal one calorie of heat.

Joule's first full description of his experiment appeared in 1847, and he made it plain that, if heat is counted, then energy is conserved. However, his work, like Mayer's, but with even less excuse, went

disregarded. Joule was not a university academician either, so that high-brow scientists of the academic world turned up their nose at him.

In fact, his paper was rejected by various learned journals as well as by the Royal Society. He was forced to present his paper at a public lecture in Manchester and then get the speech published in full by a reluctant Manchester newspaper on which his brother was the music critic.

A few months later, he finally managed to present it before an unsympathetic scientific gathering, and his presentation would have passed almost unnoticed but for a twenty-three-year-old youth in the audience, whose comments on Joule's work were shrewd enough and logical enough to rouse interest and even enthusiasm. Joule's reputation was made.

The young man who saved the situation was the British physicist William Thomson (1824-1907), who, late in life, became Lord Kelvin, by which title he is now better known.

In that same year of 1847, a German physicist, Hermann Ludwig Ferdinand von Helmholtz (1821-1894), took up the cudgels. He was not only a University academician, but he was a German (which was then the highest form), and he had achieved important results in a variety of branches of science. He was equally at home in physics and physiology.

He analyzed the situation with respect to the law of conservation of energy so clearly and cogently that it was impossible not to accept it. For that reason, Helmholtz is usually considered to be the person who established the law, to the underappreciation of the work of Mayer and of Joule.

Helmholtz went on to consider the source of the Sun's energy in the light of the law of conservation of energy, the first to take up the problem. His reasoning was faultless, and he came up with a radically wrong answer only because the existence of nuclear energy was not to be known for another half a century.

The law of conservation of energy can be known, alternatively, as "the first law of thermodynamics." The most general way of presenting it is this: "The total energy of the Universe is constant." Another way, and more familiar, is to say, "Energy can be changed from one form to another, but it can neither be created nor destroyed." Either way, the energy supply of the universe is an unchanging amount.

This sounds like an extraordinarily optimistic statement.

Since energy is required for work, and since the amount of energy available never decreases, why, then, hurray! — we will be able to squeeze work out of the Universe forever.

Unfortunately, that is not the way the Universe runs, and this first became clear in connection with the steam engine.

The first steam engine to be put to use in industry was invented by the English engineer Thomas Newcomen (1663-1729). In it a chamber was filled with steam, which was cooled and allowed to condense, producing a vacuum. The water in a mine would be sucked up into the chamber and gotten rid of. The chamber was then filled with steam again, over and over, so that the steam engine acted as a pump.

However, enormous quantities of heat had to be put into heating up the chamber each time, to get it to the point where it held steam, and that heat could not be used to do the work of pumping. Only about one percent of the heat was converted into work.

In 1769, the British engineer James Watt (1736-1819) conceived the idea of using two chambers, one of which was always kept hot and the other cold. The hot chamber could be filled with steam, which could then be allowed to escape into the cold chamber to condense, while the hot chamber was filled with more steam. In such a steam engine as much as seven percent of the heat could be turned into work. The Watt engine quickly took over and, since Watt also devised ways of converting the in-and-out motion of a piston into the turning of a wheel, his engine became the foundation of the Industrial Revolution.

A French physicist, Nicholas Leonard Sadi Carnot (1796-1832), the son of the man who first grasped the notion of potential energy, investigated the matter of steam engine efficiency.

In a book he published in 1824, Carnot was able to show that the percentage of the heat that could be converted into work by a steam engine, even under the most favorable circumstances (no friction, no heat loss to the outside world) depended entirely on the difference in temperature between the hot chamber and the cold chamber. If the hot chamber is at 110 C and the cold chamber is at 40 C, then, at the very most, 22 percent of the heat can be converted to work.

This was the first occasion on which it was shown that the presence of energy alone was not enough. What counted was "free energy"; that is, that portion of the energy that could be converted to work, and this was always less than the total energy. This was the first

glimpse of what came to be called the "second law of thermodynamics."

Carnot's discovery was generalized in 1851 by William Thomson, who had saved Joule from obscurity.

He introduced the notion of the degradation of energy. In other words, if we consider any form of energy other than heat — electricity, for instance — it can be totally converted to heat, every last bit of it. In the process, some of that energy can be converted to work, often with high efficiency. Never with total efficiency, however, for there are always factors such as circuit resistance, friction, radiation, and so on, that convert the energy to heat more or less directly without its prior conversion into work. (Of course, what is converted into work also degrades to heat eventually.)

This means that all forms of energy are converted to heat, and, if we are to get work therefore, it will have to be out of heat.

This is not impossible. For one thing, heat can be converted into other forms of energy, though not totally, never totally. Only to a certain extent — so that all forms of energy in the Universe, other than heat, are steadily declining in quantity.

But then, too, heat can be turned into work directly, without its having to be turned into some other form of energy.

To do this, however, heat must be present in different intensities, a hotter region here and a cooler region there. It's the difference in temperature out of which we can get work, but, as we extract work, the difference in temperature declines until all the heat is at the same temperature. Where a quantity of heat is at the same temperature — no matter how much heat there might be — then no work at all can be obtained from it.

We see a Universe, then, in which all forms of energy other than heat will eventually degrade to heat, and one in which this heat will even out in temperature, so that the Universe will then possess all the energy it always possessed but none of it will be convertible into work. This is sometimes called "the heat-death of the Universe."

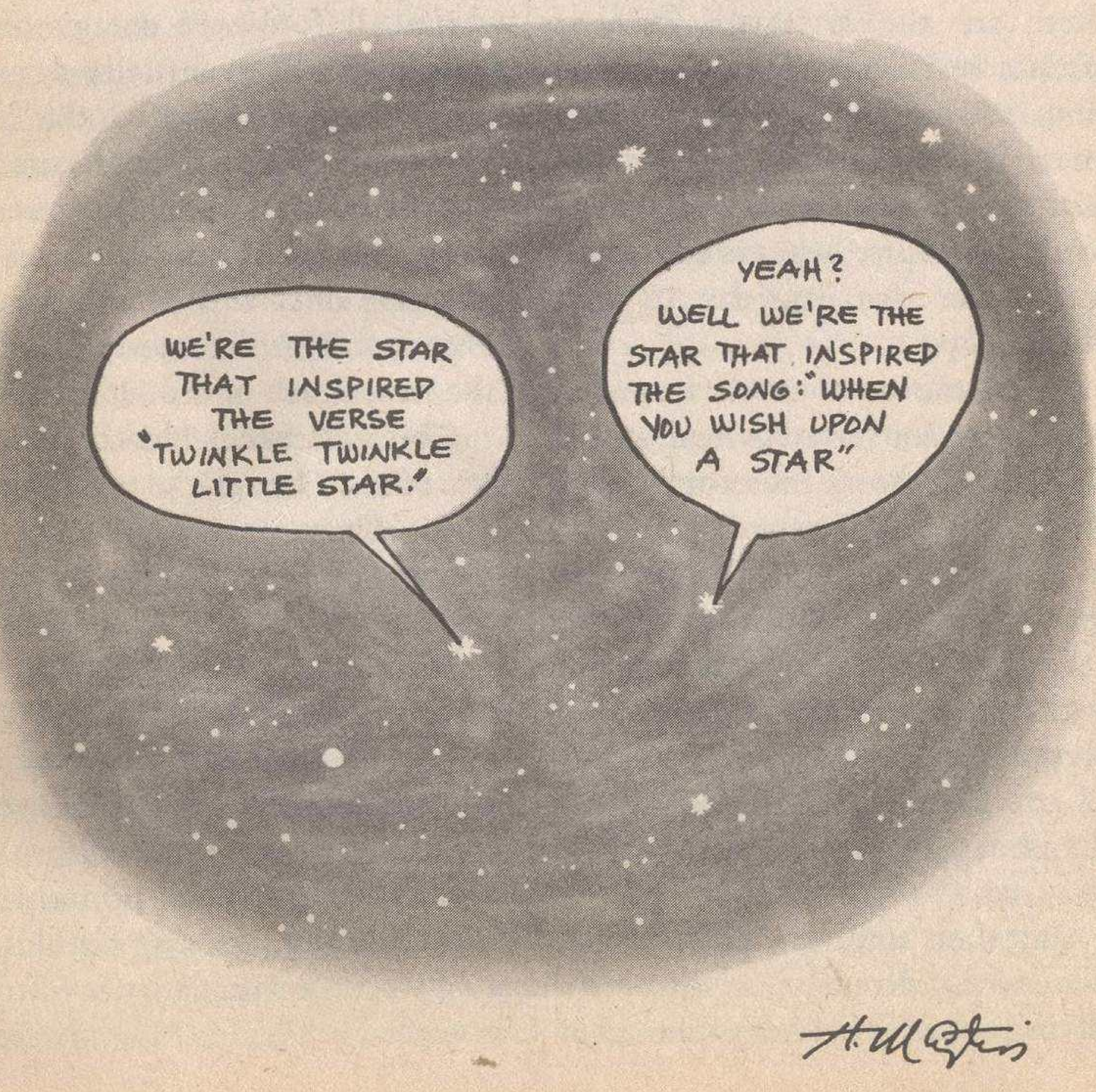
This is the second law of thermodynamics: "Though the total energy of the Universe is constant, the amount of free energy decreases steadily."

Fortunately for ourselves, the free energy supply of the Universe is enough to keep it going for trillions of years. We don't have to worry, in the course of our lifetime, or in the course of humanity's existence, that we will run out of energy in forms that are convertible to work.

Another way of looking at the second law of thermodynamics is to say that the disorder of the Universe is constantly increasing. Energy, left to itself, tends to degrade and become disorderly, and when all of it is converted to heat, and the heat is all reduced to the same temperature, the disorder is at a maximum.

In 1850, a German physicist, Rudolf Julius Emmanuel Clausius (1822-1888), worked out a mathematical expression in which one symbol stood for the disorderliness of energy. (Eventually, in 1865, he named this symbol "entropy" for no clear etymological reason.)

Using Clausius's mathematics, we can define the second law of thermodynamics as "The entropy of the Universe is constantly increasing to an eventual maximum." Because of his mathematics, Clausius is usually considered the discoverer of the second law, though this undervalues the work of Carnot and of Thomson.



SCIENCE

ISAAC ASIMOV

BEYOND LIGHT

I OFTEN DON'T get answers to my letters. I don't even expect to in many cases. Here are examples of three letters I received lately, which I answered politely, and where I expect no answers.

1) I received a letter asking to reprint a story of mine, saying, "We would like to have you waive the fee." (Naturally, they would. If they were patronizing a butcher, a baker, a grocer, or whatever, they would never think of asking him to let them have something without charge, but why the devil should a poor slob of a writer make any money out of his labors?)

So I replied saying, "I will gladly waive the fee if you, in turn, will waive the use of my story."

There will be no answer, I assure you.

2) I received a request for the reprinting of one of my F & SF essays. Its contents, the letter-writer said, would be very useful to the group he intended it for.

I wrote back to say I was delighted he would find it useful, but I pointed out that he didn't say anything about money (probably too high-minded to do so), and so I asked, "How much are you proposing to pay me?"

I'll get no answer. After all, why should he pay me? It's well-known that writers write for nothing.

3) The oddest one of all. A person wrote to say that, twenty years before, when he was only sixteen, he wrote to me saying he wanted to be a science writer and did I have any advice for him. I gave him advice which proved to be so good that he is now a science writer and is very grateful.

He apparently wished to send me a token of his gratitude, so he sent me some labels to sign—sixty (!) of them. My fingers, alas, are no longer as supple as they used to be, and signing my name sixty times would be the devil of a chore for

me. So I sent back the labels, unsigned, and said to him that if he really wanted to do me a favor to pay me back for the one I had done him twenty years ago, I wished he would choose something else.

He'll never answer.

But, of course, for me it doesn't matter. However, what if a scientist makes a great and crucial discovery and announces it in the proper manner — and no one answers.

That would be awful, and it happened to a radio engineer named Karl Jansky, back in 1932.

In 1927, AT&T had inaugurated transatlantic radio telephony, but the trouble was that there was static that made it very difficult to understand what was being said.

In 1928, Jansky (then 23 years old) was hired by AT&T to locate the sources of the static, so that perhaps it could be dealt with. Jansky built a set of antennas that were a hundred feet long and that slowly revolved. He thought that in this way he could at least detect the direction from which the static was coming.

Little by little, he eliminated most sources of static, including those that arose from the lightning of thunderstorms. Left over, however, was a hissing sound that seemed to come from the sky. It didn't come from all directions equally, but seemed to travel across the sky with the Sun. Jansky's first guess, then, was that the Sun was a source of radio waves that created static.

As he pursued the hiss from day to day, however, he found that it did *not* come from the Sun, but from a point in the sky that advanced four minutes (relative to the Sun) every day. The stars, generally, revolve about the Earth (or seem to) in 23 hours and 56 minutes, as compared to the 24 hours for the Sun. It followed, then, that the hiss came from somewhere among the stars, and it came to be called the "cosmic hiss."

What's more, it seemed to come from the general direction of the constellation Sagittarius, where the star clouds of the Milky Way were thickest, and the direction where astronomers felt that the center of the Galaxy was located. It looked, then, as though Jansky had detected radio waves coming from the center of the Galaxy.

Jansky published his work in 1932 in the "Proceedings of the Institute of Radio Engineers." It made the *New York Times* and was mentioned by the *New Yorker*. What it did not get was any sign of interest from astronomers generally. What's more, AT&T did not see that this finding was of any interest to corporate profits, and poor Jansky

was called off.

Why was this? For one thing, astronomers were entirely accustomed to looking at the Universe by way of visible light. To fool around with radio waves — about a million times as long as light-waves — did not seem to make sense.

Secondly, astronomers had no efficient way of trapping and analyzing radio waves generally, so there seemed no use in fooling around with it.

One radio engineer, however, was curious about the matter. His name was Grote Reber. He used $2,000 of his own money to build a paraboloid that was 31 feet across and that would trap and concentrate radio waves as the lens or mirror of an optical telescope would trap and concentrate light waves.

Reber set up his "dish" in his backyard in Wheaton, Illinois, and spent ten years observing the sky. He not only checked on Jansky's discovery of radio waves from Sagittarius, but detected radio sources from the constellations of Cygnus, Canis Major, and Cassiopeia.

In this way, Reber was the only radio astronomer who existed in the 1930s; he owned the only radio telescope, and he was the first to map the "radio sky." What's more, he detected radio sources from places where there were no bright stars. His conclusion, then, was that some objects in the sky delivered much more in the way of radio waves than of light waves.

He also found he had no trouble obtaining his radio sources when the weather was overcast or actually raining. The long radio waves penetrated clouds and mist when light-waves could not.

In 1940, Reber published his first paper on his findings in "The Astrophysical Review." The editor was the astronomer, Otto Struve, who found himself looking at material he had never encountered before and did not know if he could understand it. He sent a delegation to Wheaton, Illinois, to investigate the matter firsthand. They had to wait a while before Reber could demonstrate what he was doing, because his mother was using the dish as one end of her clothesline. When she was finished, Reber made the demonstration, and the astronomers were convinced.

The big catch, of course, was that in order to make things out clearly, the instrument that was catching and concentrating the waves would have to be much wider than the individual waves. Since radio waves were a million times as long as light-waves, they were also a million times as fuzzy as light-waves. The 30-foot radio telescope that Reber used was the equivalent

of an optical telescope about 1/1000 of an inch across. You could see virtually nothing with it.

To have a radio telescope that could see as clearly as the 200-inch optical telescope, you would need a single dish that was over 3,000 miles across and had an area greater than that of the United States. Consequently, however interesting Reber's results were, astronomers didn't think they would ever see anything by radio waves that would be even faintly as sharp as what could be seen by light-waves.

Meanwhile, though, in the late 1930s and early 1940s, the British were working madly on radar, for it was by radar that they could always tell when and where the numerically superior German airforce was coming to bomb England. It was radar that made it possible for the British to win the Battle of Britain.

But radar made use of radio waves, very much like those that Jansky and Reber had been detecting from the Universe. It followed that without any interest in radio astronomy whatever, the British were devising methods to detect radio waves by means far superior to those of the two pioneer radio astronomers.

What's more, without meaning to, they discovered radio waves from the sky, too.

Thus, on February 12, 1942, two German warships, the *Scharnhorst* and the *Gneisenau*, passed through the full width of the English channel from Brest, France, to Kiel, Germany, and did so undetected and safely. That got the British all excited, but it was not really their fault. If their radar had been working, they would have spotted the ships and undoubtedly sunk them, but the radars were jammed, and were not working.

That had to be investigated because the British had the horrible feeling that the Germans had discovered a new and efficient way of jamming British radar. They set their radar expert, J. Stanley Hey, to work on the matter, and in no time at all he found that it was not the Germans who were jamming the radar, but the Sun.

The jamming took place in the daytime, when the radar antennae pointed to the Sun. It took place particularly when a large Sunspot group passed across the face of the Sun so that it was facing the Earth. Obviously the Sun, and especially Sunspots, were a strong source of radio noise.

With that, earthly radar and radio astronomy melted into each other.

Once World War II was over, astronomers found themselves with a variety of devices that could be used to detect radio waves and, for

the first time, twenty years after Jansky's discovery, they grew interested in radio astronomy. (Jansky, however, died in 1950, at the age of 45 of a kidney ailment, and never lived to see what was to happen to his discovery.)

The discoveries made by radio astronomy came along very slowly, because radio waves remained fuzzy. Even by 1955, only eight bright sources were definitely detected. Among them was the Crab Nebula, the remnant of a supernova that had exploded nine hundred years before. Another was in Cassiopeia and was thought to be another exploded supernova. Then, there was a giant elliptical galaxy in Virgo and something in Cygnus that was first supposed to be a pair of colliding galaxies.

Radio astronomers had to build larger and larger dishes so as to make out things more and more sharply. The British astronomer Bernard Lovell, who had worked with radar during the war, used his expertise to build a dish that was 250 feet across and that was fully steerable.

The Germans built one that was fully steerable and was 330 feet across. It was so designed that it would not change its shape under the pull of gravity even as it changed its orientation.

The largest dish in the world was built in Arecibo, Puerto Rico. It was built into a natural valley and was 1000 feet across, but it is not fully steerable. It can only be made to watch a strip of the sky.

Even so, the Arecibo telescope could only see with the precision that an optical telescope could see if it had a lens that was a little over a hundredth of an inch across. A person's unaided eyes could see twice as sharply as the Arecibo telescope could, though of course the eyes saw light and the Arecibo telescope saw radio waves.

It didn't look as though anything larger than the Arecibo telescope could be built, but in the 1950s, the British radio astronomer Martin Ryle got an idea. Instead of building a single large dish, why not build two or three and separate them by considerable distances? Each one could be used to observe a single object in the sky from various angles. The different signals could be combined with each other and, eventually, a picture could be drawn of a radio source that would be the same as though there were a single dish as wide as the separation between the smaller dishes.

By 1955, Ryle was using 36 separate sections, all of them being manually adjusted into the positions required to photograph individual sources, and by means of

this he put together the "Third Cambridge" survey of radio sources, usually abbreviated "3C." It was this listing that eventually made the discovery of quasars possible, eight years later.

Ryle kept improving his techniques and, by 1965, he had managed this "radio interferometry" in such a way that the resolution was 200 times better than anything that could be received by a single instrument. Ryle shared in the Nobel prize in 1974 for this.

By now there are radio interferometers of the Ryle sort that are the equivalent of dishes that would be 20 miles in diameter and that work much faster than the first interferometers.

Even that wasn't the limit. The initial interferometers were connected by transmission lines that had to be laid over rough and uneven countryside. Rather than do that, radio beams were used. For this purpose, the times at which the radio beams were emitted and received had to be measured with extreme accuracy, if the data were to be properly combined. For that purpose, newly devised atomic clocks that lost less than 1 second in a million years were used.

Nowadays, various radio telescopes, scattered over the face of the Earth, and connected by atomic clocks, can see radio waves more clearly than telescopes can see light-waves. We can study pulsars, quasars, and other radio wave phenomena in enormous detail.

The radio telescopes we use now are equivalent to one that is virtually as broad as the Earth. Does that mean that we have reached the ultimate limit?

Actually, no. Astronomers dream of moving beyond the Earth, of setting radio telescopes in orbit about it. Imagine thirty devices of this sort, revolving about the Earth at a distance of 60,000 miles, or one-quarter of the way to the Moon.

If all these space dishes could be made to combine their data, the result would be equivalent to a single dish, 120,000 miles across or 15 times the width of the Earth.

In some ways, it might be even better to build a radio telescope on the far side of the moon. Everywhere on Earth, and, for that matter, in orbital space about the Earth, there are Earthly sources of radio waves that would affect the data collected by the dishes.

On the far side of the Moon, there would be absolute radio silence, at least as far as the Earth is concerned. What's more, radio telescopes could be placed in Lunar craters near the Moon's poles, where Sunlight would never penetrate, and there would be no problems resulting from changes in temperature —

and no problems relating to an atmosphere, either, for the Moon has none.

Another way of studying the Universe by means other than ordinary light-waves is to move into the infra-red. Infra-red waves are shorter than radio waves but longer than those of light.

One advantage of the infra-red is that, like radio waves, they are more able to penetrate dust and mist. Outer space, despite general feelings, is *not* a vacuum. It contains a thin scattering of dust and, in some places, the dust is not so very thin. The result is that light does not make its way through space very easily. For instance, we cannot see the center of the Galaxy. It is hidden by dust clouds. The Orion Nebula is a place where new stars are being born, but we can't watch the details of the process because it is hidden by dust-clouds. Infra-red light can penetrate all that dust, however.

Another advantage of infra-red comes in the study of very distant objects. The farther an object, the more quickly it is receding from us (thanks to the general expansion of the Universe). The more quickly it is receding from us, the more its light is shifted toward the red. The result is that very distant objects shine brightly in the infra-red, and we would want to pick up that radiation.

Infra-red has the advantage over radio sources in that whereas radio sources are highly discrete so that there are a relatively few sources while most of the sky is radio dead, infra-red, on the other hand, is to be found just about everywhere.

There is a disadvantage to infra-red, also. Visible light and most radio waves find the atmosphere perfectly transparent and reach Earth's surface, where they can be studied without trouble. Infra-red, however, is strongly absorbed by carbon dioxide and water vapor so that we don't get much at the surface. It is necessary to study infra-red from space.

The most successful infra-red detecting device was the "Infra-red Astronomical Satellite," usually abbreviated as IRAS. It weighed a little over a ton and was placed in orbit in 1983. For ten months, it scanned the sky and identified as many as 250,000 infra-red sources.

The most startling discovery it made was that the star Vega had about it a system of dust and gravel, extending out for about 15 million miles. This was considered a "protoplanetary system" since it could be viewed as being in the process of condensing into planets.

In fact, IRAS found more than 40 stars within 75 light-years of our

Solar system that had such protoplanetary systems. This made it seem very likely that stars, generally, had planets, something a number of astronomers (and almost all science fiction writers) had long thought must be true. It's nice to get evidence that seems to support the idea.

IRAS also picked up infra-red from various comets, asteroids, and strings of dust. Some galaxies proved to be much brighter in infrared than in visible light. Why this should be is not known.

At the other end of the spectrum are the X-rays, which are much more energetic than radio waves, infrared, or visible light, and therefore should be formed only in certain highly energetic processes. In general, the feeling seems natural that X-rays are formed in much smaller quantities than the longer, less-energetic waves and, therefore, must be of much less interest to astronomers.

For instance, the only heavenly object known, prior to 1962, to give off X-rays, was our own Sun, which gave them off from its extraordinarily hot corona. And, at that, our Sun gave off only one-millionth as much X-rays, as it does visible light. If the Sun weren't as close to us as it was, there would be no chance at all of detecting its X-rays, and the general feeling was that since the Sun was an ordinary star, we should detect no X-rays from the Universe as a whole.

But then, in 1962, rockets were sent into space with devices that would pick up X-ray radiation, and it was discovered, to the surprise of astronomers, that there were a number of "X-ray sources" here and there and that the energy so emitted was in some cases up to thousands or even millions of times the entire Solar spectrum of stars like our Sun. Some objects, like quasars, Seyfert galaxies and the Crab Nebula, were found to be brighter in X-rays than in radio waves.

The first important X-ray satellite was "Uhuru," launched on December 12, 1970 from Kenya. The name is the Swahili word for "freedom."

For two years it scanned the sky and came up with no fewer than 200 X-ray sources. A number of them seemed to be pulsars, that is, rotating neutron stars. However, the most exciting discovery it made was that of Cygnus X-1, which is, of all objects, the one most likely to be a black hole.

What else can we study? In the electromagnetic spectrum, there is ultraviolet radiation which consists of waves shorter and more energetic than those of visible light, but longer and less energetic than those

of X-rays.

In the 1960s and 1970s, satellites called "Orbiting Solar Observatories" were launched for the particular purpose of studying the Sun's spectrum in the ultra-violet region. There are also Orbiting Astronomical Observatories, which examine the Universe generally in the ultraviolet.

The most energetic of all the portions of the electromagnetic spectrum are the gamma rays, which I recently discussed in "Royal Gamma" (June 1991).

What does that leave us?

Subtract electromagnetic radiation and we have three forms of non-electromagnetic radiation that remain to be studied.

The first of these, and the longest known, are the cosmic rays, which I discussed in two articles, "Out of the Everywhere" (November 1988) and "Into the Here" (December 1988).

They are altogether different from any of the other radiations that bathe us in that they are electrically charged, and that some of them, at least, are the most energetic bits of radiation that we encounter. They are important as a field of study because of their enormous energies, which may reveal something about the Universe. Unfortunately, the fact that they are electrically charged means that they follow curved paths along the magnetic fields that surround the stars, and the galaxies as a whole. It is therefore completely impossible to tell the point of origin of particular cosmic rays. This hampers us a good deal in studying them.

The remaining two forms of radiation are massless and without electric charge, as is true of electromagnetic radiation, but there are important differences. Electromagnetic radiation interacts readily with matter and can, therefore, be easily detected and studied. The two non-electromagnetic forms of radiation, neutrinos and gravitons, do not interact with matter very much and are therefore very difficult to detect and study.

Individual neutrinos can travel through many light-years of lead without being stopped, but if you have trillions upon trillions of them, some will — by chance — be stopped within a matter of centimeters. As it happens, the Universe is a constant source of trillions upon trillions of them, so that they can be (with difficulty) detected.

For instance, the Sun is suposed to produce a vast number of neutrinos every second. A number of them pass through the Earth and a few of these can be stopped. Astronomers have calculated how many ought to be stopped, and for twenty years they have been work-

ing with "neutrino telescopes" designed to stop them.

Unfortunately, no more than a third the number of neutrinos have been detected, and the latest neutrino telescope detected virtually none at all. This is "the mystery of the missing neutrinos" and is inducing much head-scratching among astronomers.

The only neutrino source, other than the Sun, which we have been able to study, are neutrinos from supernovas. The supernova that exploded in the Large Magellanic Cloud in 1987 was the only one to do so when we had neutrino telescopes in place, and the only one close enough to give us a fair shot at it. Neutrinos *were* detected, and now, as better and better neutrino telescopes are built, we need only wait for more supernovas to give us further neutrinos.

That leaves the gravitons, which are so subtle in their properties that no one has been able to detect them yet. However, Einstein predicted their existence, and his general theory of relativity has yet to be disproved in any of its aspects. Astronomers are therefore certain the gravitons are there.

Gravitons are produced in unusual floods whenever a huge mass is accelerated suddenly. If two stars collide, for instance, or if a star is swallowed by a black hole, gravitons appear in huge numbers. If we could detect gravitons, therefore, we are likely to be able to study very rare phenomena that are also very extreme — and how wonderful that would be.

In fifty years, then, we have enormously supplemented what we thought, till then, had been the only clue we had to the Universe —visible light. Instead we added: radio waves, infra-red waves, X-rays, ultraviolet rays, gamma rays, cosmic rays, neutrinos, and, eventually, gravitons.

It all shows us what was invisible before, and tells us how much more exciting the Universe is than could possibly have been imagined a short time ago.

SCIENCE

ISAAC ASIMOV

STAR BRIGHT

I THINK I once wrote an introduction to one of my pieces about the twelve-year-old kid who wanted to know the second nearest star. I told him Barnard's star, 5.9 light-years away. Then he wanted to know the nearest star. I told him Alpha Centauri, 4.3 light-years away.

Then he told me he thought the Sun was the nearest star.

I always regretted I don't carry a gun. I'd have shot him down — that rotten, wise-guy, snot-nose kid.

Anyway, I'm not going to be caught a second time like that. I want to write a piece on bright stars, and I tell you right now that the brightest star in the sky is the Sun. All right?

Of course, the reason the Sun is so bright is that it's so near to us —149,500,000 kilometers, or 1.57×10^{-5} light-years away.

So let's ignore the Sun for now and ask what the brightest star in the sky is that is usually considered a star. (We don't generally think of the Sun as a star.) The answer to that is Sirius, which has a magnitude of -1.42.

Here's how magnitudes work.

About 130 B.C., the Greek astronomer Hipparchus divided the stars into six classes of brightness, which we now refer to as "magnitudes." The brightest stars in the sky are of the "first magnitude"; somewhat dimmer stars are of the "second magnitude"; still dimmer ones of the "third magnitude," then the "fourth magnitude" and the "fifth magnitude" until, finally, the dimmest stars that can be seen with the unaided eye are "sixth magnitude."

The early astronomers counted about twenty stars as being of the first magnitude. Since then, later astronomers have added a few first magnitude stars to the list, stars that were too far south for the ancient astronomers ever to have seen them.

In 1850, an English astronomer, Norman Robert Pogson, suggested that magnitudes be made more exact. If the average first-magnitude star is one hundred times as bright as the average sixth-magnitude star, and if we go down the magnitude list in five equal steps (1 to 2, 2 to 3, 3 to 4, 4 to 5, and 5 to 6) then we can suppose that a star of one magnitude is 2.512 times as bright as the star of the next dimmer magnitude. This is because five 2.512's multiplied together are equal to just about 100.

We can also calculate how much change in brightness is equal to a tenth of a magnitude or even a hundredth of a magnitude. Thus, if a first-magnitude average is set equal to 1.00, one can measure the brightness of each star and find some particular star to have a magnitude of 1.78, another of 3.91, or 5.09, and so on.

With the invention of the telescope and the increasing ability to see stars that are too dim, even far too dim, to see with the unaided eye, we have stars that are of the 7th magnitude, the 8th, all the way down to the 20's.

Since the value of 1.00 is taken as the average for the first-magnitude stars, those brighter than average must have a magnitude of less than 1. A brighter than average first-magnitude star may have a magnitude of 0.59, for instance. If a star is particularly bright, the magnitude may be even less than zero, thus forcing astronomers to move into negative numbers.

That is why Sirius has a magnitude of -1.42.

However, Sirius is not the brightest object in the sky. There are three planets that are, at times, brighter than Sirius. Mars at its brightest has a magnitude of -2.02; Jupiter, one of -2.55; and Venus one of -4.22. Venus when it is at its brightest is about 12.6 times as bright as Sirius.

Then there is the Moon, and when it is at the full and is brightest, it has a magnitude of -12.73, so that it delivers about 2,500 times as much light as Venus does, or 31,500 times as much as Sirius does.

And finally, there is the Sun, with a magnitude of -26.91, so it delivers about 470,000 times as much light as the full Moon does and a little over a billion times as much as Venus does.

Nevertheless, let us eliminate the Sun, the Moon, and brightest planets and get back to Sirius.

Why is Sirius so bright? Well, for one thing, it's quite close to us, only 8.63 light-years away. If it were farther away, it wouldn't look as bright.

Nor is closeness the only answer. The star Alpha Centauri is closer

to us than Sirius is; it is only 4.27 light-years away, and yet Alpha Centauri has a magnitude of -0.27, so that it is only about one-third as bright as Sirius.

The answer is how bright the two stars are. Alpha Centuri is just about as bright as the Sun. Sirius, on the other hand, is about 23 times as bright as the Sun.

Obviously, then, in judging the brightness of a star, we must know first how far it is and second how "luminous" it is. For instance, Barnard's star is only 5.9 light-years away from us, but it is so non-luminous (only 0.00036 times as bright as the Sun) that even at that close distance, we can't see it without a telescope.

For that reason, astronomers have worked out a quantity called the "absolute magnitude." This is not the magnitude as a star appears in the sky, but is the magnitude that would exist if every star were at a fixed distance.

The fixed distance is 10 parsecs, where a parsec is equal to 3.26 light-years, so that the stars would be 32.6 light-years away.

Suppose, for instance, the Sun were ten parsecs away from us. It would shine with a magnitude of about 4.7. That would be its absolute magnitude. If Sirius were ten parsecs away, it would have a magnitude of 1.3. It would still be a first-magnitude star, but it would be appreciably dimmer than it is now because it would be farther away, at ten parsecs, than it is in reality when it is only a quarter of a parsec away.

Now, you see, we can really ask a question — not what is the brightest star in the sky in appearance, but what is the brightest star in our neighborhood in actuality? (We have to confine ourselves to stars in our own neighborhood, for there may be far distant stars that are brighter still, but which are too far away for us to be able to study them in detail.)

If, then, we consider only the stars within 1,000 light-years of ourselves, we come across the star Rigel.

Rigel is a star in the constellation of Orion, the Hunter. It is located where the foot of the Hunter is usually pictured, and "Rigel" is from the Arabic word for "foot."

Rigel would seem to be an ordinary first-magnitude star, with a magnitude of 0.14 — the seventh brightest star in the sky. There is a catch, though. Rigel is about 850 light-years away from us, much farther than any other first-magnitude star. Yet even at that distance it is first-magnitude.

This means that it has an enormous luminosity. Personally, I find a different figure for it in every

reference book I consult, but I have an article on the subject that has just been published, and it gives Rigel an absolute magnitude of -9.9, so that it is nearly a million times as luminous as the Sun. If Rigel were ten parsecs away from us, it would shine with about 100 times the brightness of Venus.

Rigel has a mass about 25 times that of the Sun, and it stretches out over a diameter of 65 times that of the Sun. If Rigel were in the Sun's place, it would almost fill the orbit of Mercury.

Rigel would not be nearly as large as a red giant, such as Betelgeuse or Antares, but it would be much hotter. Wheras a red giant is cool (that's why it is red) Rigel is a blue-white star with a surface twice as hot as that of our Sun.

Rigel can't possibly have planets with intelligent life on them or, indeed, planets with any form of life. Not only is Rigel so hot that planets must circle it at enormous distances to be cool enough for life — but there is something worse.

Rigel has an internal temperature of 100 million degrees as compared to 15 million for the temperature at the center of our Sun.

In order for Rigel to maintain that temperature, it must be consuming hydrogen at an enormous rate. Even though it has 25 times as much hydrogen as the Sun has, the rate of consumption is such that Rigel would use up its supply far, far sooner than the Sun does.

Whereas our Sun will continue to burn at an ordinary rate for billions of years, Rigel will remain as it is for no more than a million years or so; then with its hydrogen content decreased, it will expand to a red giant and collapse in a blaze of supernovahood.

This means that whereas our Sun has supplied a decent amount of heat and light for five billion years now and will certainly continue to do so for another five billion, Rigel can do nothing of the sort. The Sun has time for its planets (or for one of them, anyway) to develop life and even intelligent life. Rigel has no chance of doing any such thing.

Rigel, unlike our Sun, does not shine in single blessedness. (Few stars do.)

Back in the 1830's, the German-Russian astronomer Friedrich G. W. von Struve spotted a star nearby Rigel.

The star, Rigel B, is about 625 billion kilometers from Rigel A, or about 200 times as far as Pluto is from our Sun. Since the discovery of Rigel B, it has been observed to be moving along with Rigel A, and this makes astronomers think the two stars are gravitationally bound.

Of course, they should be circling each other, but at a distance of 625 billion kilometers, the orbital movement is very slow.

In 1908, a Canadian astronomer, John Stanley Plaskett, reported that Rigel might be a very close binary star. He noticed that the spectral lines shifted regularly from a movement toward the red to a movement toward the blue. This made it seem that Rigel was advancing toward us slightly and then receding from us and doing so in regular fashion.

A logical explanation for such a phenomenon is to suppose that Rigel is circling another star very close to itself, so that the orbital motion carries it toward us and away from us. The second star would be a dim one and would not be seen against the blaze of Rigel itself.

However, Plaskett seems to have been wrong. In all the years since 1908, despite the improvement of instruments, no close companion star to Rigel has been detected. But, in that case, why does Rigel move in and out, so to speak. Apparently, the outer atmosphere of Rigel pulses, and that is what produces the effect.

In 1937, however, it turned out that Rigel B was a close binary star. This time there seems no question, for the spectral lines of both stars were seen and they orbit each other every ten days.

Both companion stars are distinctly brighter than the Sun. Rigel B is 100 times as luminous as the Sun, and Rigel C is 50 times as luminous.

It strikes me that if there is a planet that circles Rigel C, it would probably see three suns in the sky, not stars, but suns (shades of my story "Nightfall").

Rigel is such a brilliant star and is so hot at its core that it apparently emits puffs of matter in an irregular fashion. Some of it seems to fall back to the star, but some keeps on going. If Rigel were located where the Sun is, some of these puffs would carry gas to Jupiter's orbit in a month. As a result of these puffs Rigel is losing about 1/100 of its mass in a million years.

The star that burst in a supernova in the Large Magellanic Cloud in 1987 was a lot like Rigel, only worse. It gave off larger puffs and ejected a great deal of mass. Rigel apparently isn't sufficiently extreme to become a supernova just yet, however.

The Italian astronomer Pietro Angelo Secchi was the first to suggest that stars be divided into classes based on their spectral appearance. Between 1864 and 1868, he studied the spectra of 4000 stars

and found there were marked differences between them. He therefore divided the stars into four classes.

As time went on, they were divided into more classes. Originally, they were to be listed in order of the alphabet but, again, as time went on, this was found to be inadequate. Right now, the stars are divided into the following classes: O, B, A, F, G, K, M, R, N, and S.

The order is remembered without trouble by means of the following mnemonic: "Oh, Be A Fine Girl. Kiss Me Right Now, Sweetheart." The last three items, R, N, and S, refer to rather unusual stars and are generally ignored.

Of the remainder, the spectral classes give the order of luminosity, from O, which is the most luminous, to M, which is the least. In general, the number of such stars increases with dimness so that the brightest stars, O, are the least numerous and M, the dimmest stars, are most numerous.

Thus, our Sun is a G-type star, and about 10 percent of the stars in our Galaxy are G's. F-stars are more luminous than the G-stars and there are fewer of them. About 3 percent of the stars in the Galaxy are F's. About 1 percent are A's and about 0.1 percent are B's.

Only one star out of every 25,000 in the Galaxy is an O-type. Even so, there may be as many as 10,000,000 O-stars in the Galaxy. We are not very aware of them because most of them are so far away we see them only as dim objects, if at all. Some are hidden by dust clouds and some are hidden by clouds of their own making for they give off matter in great quantities. The brilliance of Rigel, though it is not an O-star, arises from the fact that of all the stars that are B or O, it is the closest.

For instance, there is an O-type star that is so far away, it doesn't even have a name but only a catalog number. It is Cygnus OB2 #12. Its absolute magnitude is -9.9 so that it is as luminous as Rigel. This star, however, is in a cloud of dust that dims it 10,000-fold so that it doesn't seem anywhere near as luminous as it ought to be.

Then there is a star called HD 93129A, which radiates a great deal of its light in the ultra-violet, which is, of course, invisible to us. If all the light it radiates, ultra-violet and all, were lumped together, it would have an absolute magnitude of -12, which would make it more than six times as luminous as Rigel and about 5 million times as luminous as the Sun. It happens to be 11,000 light-years away so that you need a telescope to see it, but if you put it at the standard distance of 32.6 light-years, it would rival our full Moon

in brightness.

The bright B and O stars often shine in association. That is, there are a number of them that are moderately close together. The notion is that they all formed out of one gigantic cloud of dust and gas and that ordinarily they would drift apart. They have not had time to do so, however, for their lifetimes are very short.

A B-star is liable to exist on the main sequence for ten million years (as compared with 12 billion years for our Sun). An O-star might last on the main sequence for less than a million years.

That is why there are so few of these extremely bright stars. In the first place they have to form out of enormous dust clouds, and these don't exist in great numbers. In the second place, once they are formed, they don't remain as they are very long, but, relatively quickly, explode as supernovas.

Let's move to the other end of the star classification, the very dim stars.

There is always the impression that what one sees (or detects) is what exists and nothing else need be worried about.

For instance, for thousands of years, human beings looked at the stars and felt that only those stars they could see existed. A star that was too dim to see was a contradiction in terms. What good was it if you couldn't see it? Why should God bother to create it?

Of course, with the invention of the telescope, we discovered that there were innumerable stars we could *not* see with the unaided eye.

The situation may be similar in the case of the stars of different spectral classes. The dimmest stars we can make out are those of the M-classification, and so it is taken for granted that these are the dimmest stars there are.

Not necessarily so!

You have dust clouds forming the stars, and the smallest dust clouds are the most common. They form the M-stars. But what about dust clouds that are smaller still. It is a mistake to think that everything stops just because that's all we can see.

Still smaller dust clouds will form still smaller stars, and these "sub-M stars" (my own name) would be far more numerous than the M's themselves. They would be so small indeed that they would not have enough mass to set up a fusion reaction at their center. At least, they wouldn't set up the hydrogen-hydrogen fusion reaction that powers all the stars we see.

It might be that they would set up subsidiary systems of creating energy — in very small amounts —

and would, if they shone at all, do so just barely.

These barely-shining dwarf stars are called "brown dwarfs" because they are barely red-hot. Astronomers are searching for them. After all, if they exist in large numbers, they may add significantly to the mass of the Universe and, in effect, explain, at least in part, the "mystery of the missing mass."

For another, they would help us understand how stars are formed.

Unfortunately, however, astronomers have not yet made a clear discovery of brown dwarfs.

As I said earlier, stars brighter than G-type don't last long enough to give rise to planets on which life has time to form beyond the bacterial stage at the most.

What about moving in the other direction and going on toward the K and M stars. The K stars can last on the main sequence about 25 billion years, and the M stars can last, easily, 100 billion years. They are small and don't have much hydrogen, but they dribble it out very slowly, you see.

Surely, they have plenty of time to develop planets that can in turn develop life. Some of the large K's may actually do so, for all we know.

The trouble with K and M stars is that they are cool stars, and, in order for a planet to be suitable for life as we know it (in order for it to have liquid water, for instance), it must exist fairly close to the star.

It can do so, but as a planet gets closer and closer to a star, the tidal effect increases very rapidly, and once it is close enough, it ends up facing one side to the star, just as the Moon faces one side to us.

A planet facing its star steadily gets to be hot on that side, even if the star is comparatively cool. The night side is, of course, extremely cold. The planet is therefore simply unsuitable for life.

This is a shame, for together, the K and M stars make up 7/8 of all the stars in the Galaxy.

That leaves us with the G-stars as a possible abode of life. There are about 200,000,000,000 stars in the Galaxy, and if the G-stars make up 10 percent of them, that means there are still 20,000,000,000 stars capable of producing life.

Of course, a great deal depends on the location of the stars. We now know that the center of the Galaxy (where most of the stars are located) is a place of enormous energies and violence which life could not withstand. A G-star would have to be located in the suburbs, in the spiral arms and nowhere near the center — as in fact our own Sun is located.

As it happens, about 10 percent of all the stars are to be found in

the spiral arms, so that still leaves 2,000,000,000 G-stars in the spiral arms.

But then, of course, a star that is suitable for the development of life may be a binary star, which precludes a proper orbit for a planet circling one of the Suns. Or even if it is a single star, it may simply not have a planet that is in the proper range, that is close enough to the Sun to have liquid water and far enough away so that the water is not boiling.

Our own Sun has nine planets, several dozen satellites and uncounted bodies of other size and, of them all, only Earth exists under conditions that make life possible. We would have to assume that most G-type stars, however well-located, simply don't develop a planet suitable for life.

Let us suppose (a pure guess) that only one such star out of a hundred will develop the necessary planet. In that case, there will still be 20,000,000 G-stars with a useful planet circling them.

It is my belief that any planet that possesses the physical and chemical attributes that make life possible on it, will quickly develop that life. We only know one example of this, Earth itself, but it began to develop life almost as soon as Earth stopped being bombarded by huge meteorites.

There is a catch, though. Life is life, but it is not intelligence. How long would it take a planet to develop intelligent life, to develop a technological civilization?

Again, we only know one example of this, our own, and the fact is that life existed on Earth for at least 3.5 billion years and intelligent life (at least life capable of producing art and useful inventions) only about 50,000 years ago. Our technological civilization is only a couple of centuries old.

Under the circumstances, it does not seem likely to me that the Galaxy, though full of life, is necessarily full of civilizations. Still, there may be hundreds in existence, perhaps even thousands.

I don't think any of them will be coming here. There are scientists who think that, little by little, a civilization that is in existence will explore the Galaxy, and the fact that none have reached us in our history is an indication that such civilizations don't exist.

I don't believe this. I think that civilizations are thousands of light-years apart and that they are not going to try to cover such distances just to reach us — or even just to explore. I do think, however, that messages may be sent out, if we would only learn to detect them.

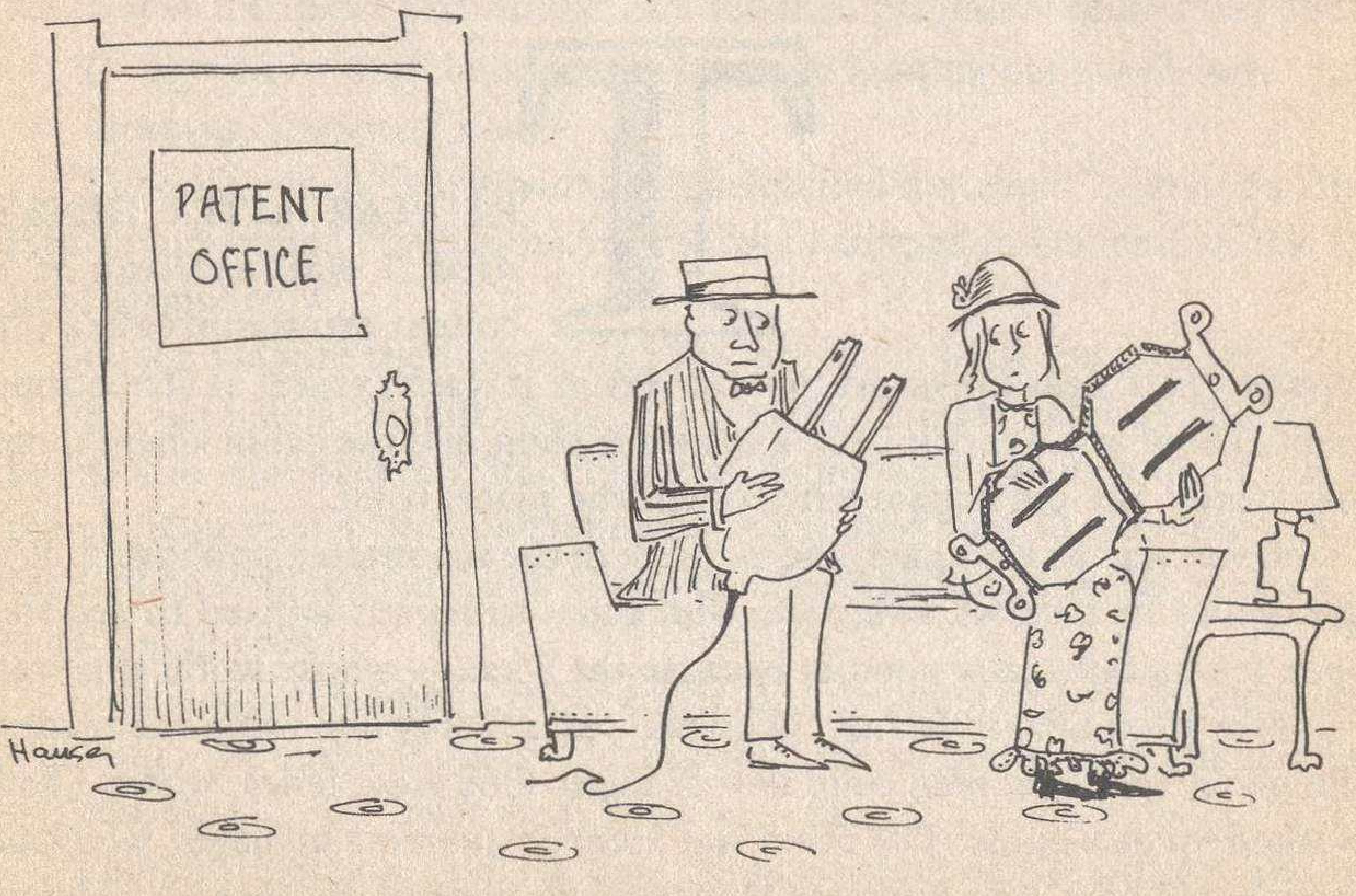
Astronomers are interested in SETI ("Search for Extra-Terrestrial

Intelligence"). It would cost a lot of money, and the chances of coming up with something useful is virtually zero. So why bother?

Well, 1) Astronomers would have to build new forms of radio telescopes to do the job, and it would always be useful to have new devices, even if they do not do the job for which they are designed.

2) In searching for messages, then, even if we don't find them, we are certain to come across all sorts of things that we now have no notion exists. Pulsars and quasars were discovered serendipitously and not because anyone was looking for them.

3) If we do detect what seem to us to be messages, then the chances are that we will not be able to interpret them. Even so, it would be interesting to see that the messages exist, that a civilization more advanced than our own is to be found in the Galaxy, and that it has not succeeded in destroying itself. After all, we are on the point of destroying ourselves, and the discovery that this is not necessary might be a cheering matter.



SCIENCE

ISAAC ASIMOV

OF HUMAN FOLLY

I WAS ONCE interviewed on the radio, and the interviewer seemed fascinated by my skepticism. He kept asking if I believed in this and if I believed in that, and I answered, "No," every time.

Finally, he decided he would get down to the nitty-gritty. He said, "Do you mean to say," and his voice grew sepulchral, "that you don't believe in the — Devil?"

I jumped a little. "The Devil," I said. "I never met anyone who believed in the Devil or who gave him two thoughts. Why don't you ask me," and my voice grew sepulchral in imitation of his, "if I believe in — God!"

But he wouldn't ask any such thing. He changed the subject. Clearly, he was afraid that if he asked me that, I would answer, "No, I don't" (which is certainly what I would have said), and he feared the reaction of his audience.

I didn't fear it, but that lily-livered coward did.

I once gave a talk to four thousand people in Richmond, Virginia, and a very good talk it was. I spoke of the manner in which we were destroying our environment, and I was very emotional about it, too.

So there came the question-and-answer period, and a man stood up and said, "Professor Asimov, why are you so worried about destroying the environment, when Jesus Christ will be returning in the Second Coming before long."

(I stared at him in disbelief. Presumably, I felt, he had decided that if Jesus came back and found a single patch of the environment unpolluted, a single bit clean and decent, he would be very annoyed with us.)

I answered quietly, "Why on Earth should I believe any such fool thing as the Second Coming when I have the good luck not to be a Christian."

There was an instant intake of

several thousand breaths as everyone stared at someone who had the audacity to say — in public, yet — that he was not a Christian, and who acted happy about it. I am sure that quite a few people expected a lightning bolt to come down and smear me all over the place, but, of course, that didn't happen.

I grinned happily, answered other questions, finished, collected my check, and went back to my hotel.

People believe in the existence of ghosts, of zombies, of leprechauns who watch over pots of gold, and banshees who wail at a forthcoming death, of werewolves, of vampires.

Why not, in the old days, when very little was known about the world and where all these things might well exist.

Today, however, we live in a world of science and rationality, and there are *still* people who believe in all that nonsense.

Why is that?

For one thing, all these beliefs are dramatic. They are frightening. Tell the stories around a campfire and feel the shivers.

And what have we rationalists to say in response?

All we can do is deny. There are no such things as ghosts, zombies, leprechauns, banshees, werewolves or vampires.

What we're doing is presenting you with a dull world that you don't want to accept.

Then, too, most people grow annoyed with these all-knowing scientists who stick their noses in the air at things you want to exist. If you want your castle haunted by a headless ghost, you don't want some wise guy saying, "Nonsense!"

The result is that you continue to believe things that are absolutely the crudest junk.

For instance, about a hundred years ago, two young women with nothing much to do cut out a couple of figurines that looked like fairies and took photographs of themselves and their fairies. Anyone looking at the photographs with half an eye could tell they were fakes, but that didn't help Sir Arthur Conan Doyle.

Sir Arthur had made himself world-famous as the author of the Sherlock Holmes stories, and Holmes was the very epitome of the rationalist. In real life, however, Sir Arthur believed in spiritualism and a mess of other follies. How is that possible? Don't ask me.

In any case, Sir Arthur saw the pictures of the fairies and fell for them. He went around for a long time insisting that fairies existed, and using those faked photographs as evidence.

Of course, scientists are human, too, and can fall for foolishness,

especially in their old age. Sir William Crookes, a first-rate British physicist, in his old age grew interested in spiritualism and was easily fooled by mediums. (It is simple to be fooled, if you *want* to be fooled.)

Robert Hare, an American chemist, grew interested in spiritualism late in life and invented a device by which he thought he could communicate with spirits. He wrote a fat volume on the subject in 1854. A German physicist, Wilhelm Eduard Weber, also turned to spiritualism late in life, as did a Russian chemist, Alexander Butlerov.

I had an editor once, John W. Campbell, Jr., whose hobby it was to prove scientists wrong. He would believe anything — anything under the sun — as long as what he believed tended to show that scientists didn't know what they were talking about.

One of the things he used to do was make a collection of all the scientists who accepted spiritualism and use that as a proof that there was something to it.

I would say, "John, why don't you put together a much larger collection of all the scientists who said that spiritualism was phoney and prove there's nothing to it." However, he wouldn't listen to me.

* * *

Of course, there are fads and foolishness that are quite modern. You don't have to go back centuries to pick up material on ghosts and fairies.

What about "unidentified flying objects" (or "flying saucers," as they are often called)? John Campbell was great on flying saucers. He accepted them and hugged them to his bosom. So do millions of people who know nothing about astronomy.

For nearly fifty years, now, people have been talking about flying saucers, and have presented all kinds of silly data supporting them. Right now, for instance, we have lived through a rash of books about people who were kidnapped by aliens in flying saucers and then returned — but for what reason is never explained.

In all that time, though, nothing has *really* developed as a result. It's all fairy tales.

I get so tired of it, you have no idea. After all, I'm a science fiction writer and everyone knows it, and there is always a feeling that a science fiction writer has an "open mind."

They all say to me eagerly, "Do you believe in flying saucers?"

"No," I say, sharply, and they're always so disappointed.

When I hear a scientific advance announced on television, I immedi-

ately stiffen with disbelief. In the first place, the people making the announcement do not know science and are interested only in saying something sensational.

In fact, any scientist who allows his discovery to be announced on television, instead of in the scientific journals, earns my distrust at once. He is not after scientific truth, but after a Nobel Prize or a lot of money and fame.

About two years ago, we had a marvellous example of this. Two chemists announced the existence of "cold fusion." This meant they could make hydrogen fuse together and produce enormous quantities of energy, and do it at ordinary temperatures.

Cold fusion meant a *cheap* source of virtually eternal energy. It also made physicists, who had been looking for hot fusion for nearly forty years, look foolish.

Very few people knew what cold fusion was or how it worked, but it was enough that it was cheap and made scientists look foolish. Of course, this was emphasized on television and for a while, cold fusion was the hottest thing in the news.

There was only one small catch. It didn't work.

That doesn't stop people from being eager about it. Two years have passed in which absolutely nothing has developed out of cold fusion, and people still come to me with stars in their eyes and say, "What do you think of cold fusion?"

I answer coldly, "It's a mess of nonsense."

And they go off unhappily. That's not what they want to hear.

Even more recently, the television began hopping up and down again. It seems that some scientists had announced the existence of a youth serum, and if there is anything everybody wants (including me, for goodness sake) it's a youth serum.

It was based on human growth hormone and, if smeared on the skin, it removed wrinkles, gave it a youthful shine, and, presumably, made the whole body young.

My dear wife, Janet, was watching my face as this was being announced and she said to me, "Don't you think there's anything to it, Isaac?"

"No," I said, "I don't. Here's what I think will happen. On closer examination, they will find out that: 1) the effect is purely superficial, just smoothing out the skin; 2) it will turn out to be purely temporary, and 3) it will turn out to have unpleasant side-effects. After a little while, this stuff will vanish from the television tube and never be heard of again."

I was completely and entirely

correct, but I got no medals for being right. The public wanted a youth serum.

Some years ago, a new medical fad arose. The world is full of medical fads, incidentally. Despite the fact that modern medicine works so well, people are always looking for something better. They want "the laying on of hands," they want "psychic surgery." Most of all, they want "prayer." Heaven only knows how many people, who are quite ill, have been prayed over till they were quite dead. It doesn't seem to bother anyone. The dead man just didn't have "enough faith."

Anyway, the fad I am now referring to involved many needles and was called "acupuncture." It was derived from Chinese medical practice, and the idea was that if needles were stuck into the body in appropriate places, it acted as an anesthesia, or it cured arthritis, or who knows what.

People jumped all over it. Personally, I wouldn't want needles stuck into my body for any purpose, but it proved rather popular. For one thing, it was cheap. For another, it made fools of orthodox physicians, and it is always fun to make fools of scientists.

What astonished me is that my very own doctor grew enthusiastic over acupuncture. He had travelled much in China and had become an old Chinese hand, so that he was very impressed by "barefoot doctors" (whatever they are) and by acupuncture.

I asked my doctor if the needles were plunged into the body along the lines of nerves so that they could have some sort of neurogenic effect. He said, "No, it had nothing to do with the nerves."

"How, then," said I, "can it act as an anesthetic and do all the other things it is supposed to do?"

Well, I don't know," said my doctor, "but it seems to work."

"Listen," I said. "You're crazy."

And he was, at that moment, for acupuncture has disappeared because it *didn't* work.

Incidentally, this business of "it seems to work" is probably the strongest support any piece of folly ever receives. Nothing is ever so silly and stupid that there aren't people who insist that they've tried it out and it worked. There's not an anti-cancer nostrum ever invented that didn't obtain unsolicited letters from people who insist they had been cured of cancer by it. After all, anything will work — at least temporarily — if you're sure it will.

I am president of the Dutch Treat Club and, a couple of years ago, someone arranged the head table and omitted me. I wandered round

and round the table reading the cards and my name simply wasn't there. I didn't really care because the people at the head table were not of great interest to me. Still, I felt that I ought to uphold the honor of the Presidency, so I demanded a seat at the head table.

It served me right. They squeezed me in, to my horror, between Shirley Maclaine and her daugher. Shirley Maclaine is an actress who I admire less than any actress I know. How I squirmed and tried to avoid talking to either one of them.

Shirley Maclaine has this weird notion that involves transmigration of souls. I believe she thinks she was once Cleopatra. (Poor Cleopatra!) If you try to argue with her, her answer is, "This is *my* truth." In other words, she considered truth subjective and that she has the right to believe anything she wants. Since out of his nonsense, she has made a great deal of money, I suppose we can't very well do much in the way of sneering.

This matter of transmigration of souls, however, which many people believe in —

Who doesn't want the thought that after he dies he will be reborn and have a brand-new life.

The catch is: What kind of life will you have? Right now, there are 5,400,000,000 people on Earth, and the vast, vast majority, are starving Sudanese, drowning Bangladeshi, shivering Kurds, impoverished Latin Americans, and so on. The chances are a few million to one that you will be born one of these pitiful creatures and live out a relatively short and miserable life.

My own life has been a marvellously good one. Do you think I want to take a chance on another life that will be a marvellously bad one? Far better to die and greet nothingness.

Of course, there are many people who believe that after they die they will go to Heaven, but it seems to me that almost everyone will admit that, thanks to a kindly all-merciful God, far more people are slated for Hell than for Heaven.

I, myself, since I am an atheist, am surely slated for Hell. Fortunately, since I am absolutely certain that Hell does not exist, I am not trembling at the possibility.

It's amazing how *good* change tends to be rejected.

In the tenth century, the Holy Roman Emperor Otto II had married a Byzantine princess and she brought in some of the more civilized aspects of life from the East.

For instance, she made use of forks.

The good people of Otto's court objected furiously to the sissified

novelty. They thought one should not toss food into the mouth like hay into a barn. They also went around saying, "Fingers were made before forks."

I suppose you can't blame these boors altogether. They knew nothing about personal hygiene and the germ theory of disease, and they tended to die like flies from infections of all kinds. However, even as late as the 17th Century, Louis XIV of France ate his meals with his fingers.

In the 1700s, in Connecticut, the first umbrella was designed and put to use. I'm amazed that no one thought of it earlier. I'm even more amazed that people who observed its being used were dreadfully annoyed.

It was a case of putting all the blame for ignorance upon God. The argument was that if God wanted you to be wet, he should make you wet, and that it was blasphemous to try to keep the rain off.

Of course, prior to umbrellas, people wore heavy greatcoats with hoods to keep the rain off. That, apparently, was all right, but not an umbrella.

However, God lost that argument, for people enjoyed not getting wet in a rainstorm, and umbrellas became a piece of haberdashery that the Englishman, for instance, is never without.

In the 1750s, Benjamin Franklin invented the lightning rod, which kept lightning from hitting houses and barns. You'd think everyone would be delighted. Not at all. God came into the picture again, and there were ecclesiastics of all kinds who objected strenuously to the use of lightning rods. After all, if God wanted to hit someone or something with lightning, he had the right to do so without interference.

In 1755, an enormous earthquake and tsunami destroyed the city of Lisbon, in Portugal. The ministers in Boston rose in their wrath and said that Lisbon was destroyed because Bostonians were putting up lightning rods. This certainly didn't speak very highly for God's marksmanship.

But, as a matter of fact, God lost out again. Nobody wanted to be hit by lightning if it could be avoided and, eventually, lightning rods went up even on churches.

In the 1840s, anesthesia came into use, and one thing it was used for was to ameliorate the pains of childbirth.

That drove the ministers almost crazy, because God had said to Eve that "in pain and sorrow shalt thou bring forth children," and the ministers were absolutely intent on making sure that all the descendants of Eve so suffered.

But God lost again. Quite apart

from the fact that women generally didn't want to bring forth children in pain and sorrow, Queen Victoria made use of anesthesia during childbirth. At once the furor died down and the ministers were silent. After all, God was only God, but the Queen was the *Queen*.

I am a member of the Baker Street Irregulars, or, at least, I was. The Baker Street Irregulars idolize Sherlock Holmes. I'm not an idolator of the man myself, but I didn't mind attending the meetings.

There was a catch, however. All the Baker Street Irregulars try to be as much like Sherlock Holmes as possible. Thus, they virtually all wore deer-stalker hats. Well, there's nothing much wrong with that. I have a deer-stalker, too, and I have worn it on occasion.

However, Sherlock Holmes was a fiendish smoker of harsh and smelly tobacco, and all the Baker Street Irregulars, after the annual banquet, would light up their foul tobacco and puff away.

It drove me crazy. I objected strenuously, but it did no good. I said to them, "Sherlock Holmes also made use of cocaine. How many here are also making use of that."

That didn't bother them. They continued to smoke. It is not that I can't stand the smell (which I can't) and that it clings to my clothes (which it does) but that I am forced to inhale the noxious fumes myself. I become a "passive smoker" and my life is thereby shortened. Why on Earth should I be willing to shorten my life in order that someone else should get the pleasure out of smoking.

So I no longer attend the meetings of the Baker Street Irregulars.

I had a similar problem with the Mystery Writers of America. I had been appointed one of the members of the board, and so I attended a board meeting. I found that everyone at the meeting smoked.

I never attended another board meeting.

Many people have lucky objects to fend off disasters. We all know about rabbits' feet, about lucky coins, and so on. Without them, terrible things will happen to you.

We're all brought up to believe in things like that. (If your parents don't teach you, the other kids will.) When I was a kid, I was painstakingly taught that in order to ward off the evil eye, I must be careful to spit three times.

There were things of terrible ill-omen. I believe that when a shroud was sewed for a dead body, the needle used to do the sewing was filled with omens of death. It could not be kept in the house and so it was thrown away in the street.

One day, coming home from school, I came across a needle lying in the street. I happened to know that if you saw a pin and picked it up then all the day you'd have good luck. Picking up a needle seemed to me to be even more effective. So I picked it up and brought it home proudly to my mother who, I thought, would pat me on the head and tell me what a good boy I was.

No such thing!

She screeched an unearthly screech, snatched the needle from me and threw it out into the street again. I am convinced, looking back on it, that she expected me to die shortly — but, of course, I didn't.

You can imagine how far you will get if you try to reform these good- and bad-luck idiots. Tell an actor that it doesn't matter if he tosses his hat on the bed. Tell him he doesn't have to say "break a leg" when a fellow-actor goes out on the stage. Tell him it's all right to say "Macbeth" instead of the "Scottish play" — and you will get nowhere.

Then there are people who, having said something smug, will look about desperately for a piece of wood. They hit it with their knuckles and say, "Knock wood." (These days when so little wood exists, they must go crazy.)

If you say to them, "Why do you knock wood?" they will answer, "It's bad luck if you don't" — if they bother to answer at all.

There are people who will not pass under a ladder that is leaning against a wall, or who have a virtual fainting fit if a black cat runs across their path.

"Why does that bother you?" you might ask.

"Bad luck," they gasp.

To have so many ways of developing bad luck simply makes one terribly unhappy. Tell them gently that there are no such things as good-luck objects and bad-luck objects and you are quite likely to get a punch in the nose.

People don't want their follies withdrawn from them.

There are also curses on objects, usually on valuable ones. Or at least, so people believe. We have all heard of famous diamonds that carry a curse. We read stories of families who labor under a curse from generation to generation. It's hard to believe that anyone can accept such nonsense — but they can.

Just in order to end this essay on a light note, though, I will tell you my favorite curse story.

A man in an airplane couldn't help but notice that a very beautiful woman sitting next to him was wearing a monstrous diamond.

He stared at it as unobtrusively

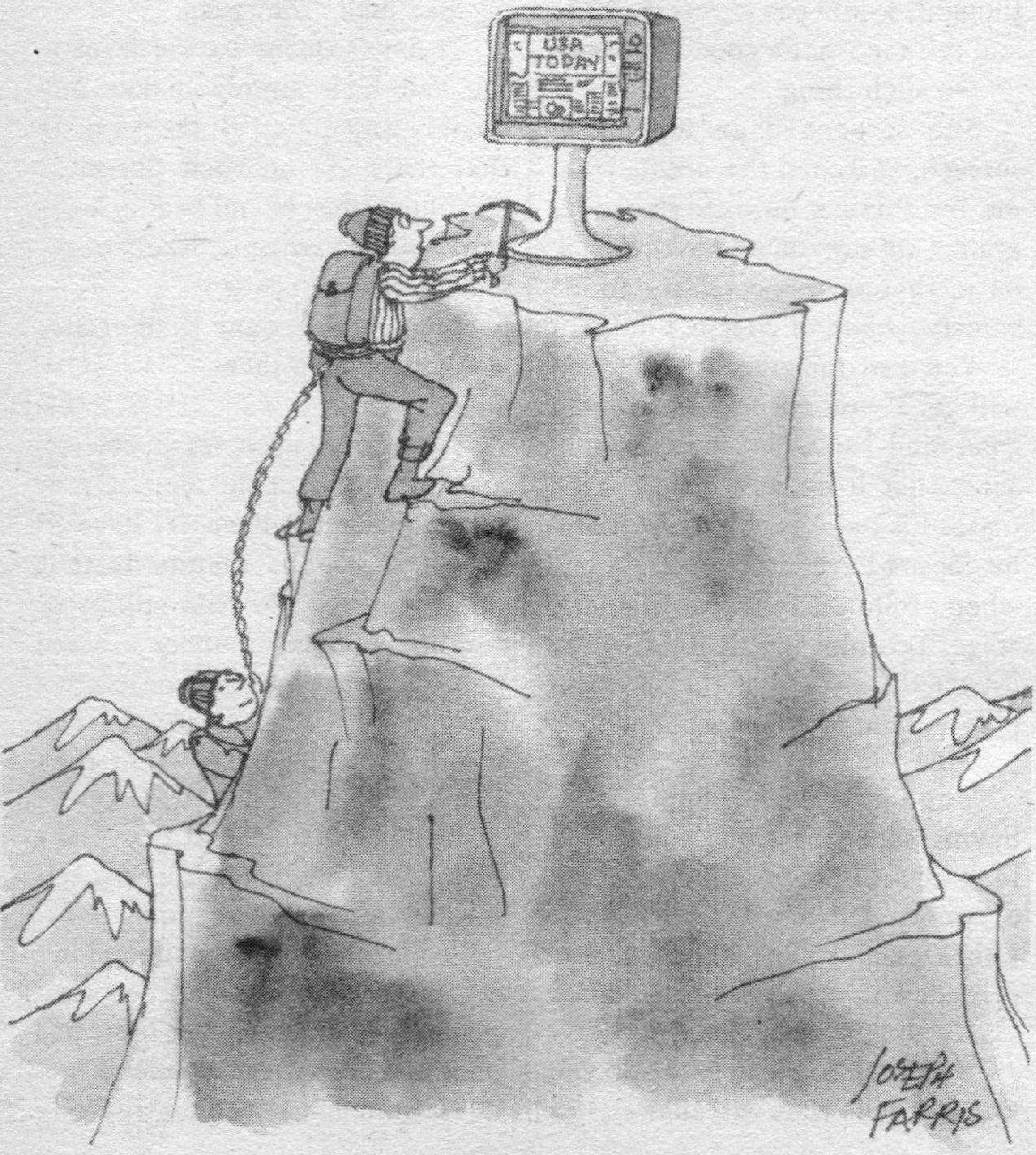
as he might, but finally, his curiosity overcame him.

"Pardon me," he said, "but is that a real diamond?"

"Real as anything," said the woman. "It's the famous Kripnitz Diamond. It comes with a curse."

"It does!" said the man, more interested than ever. "What is the curse?"

"Mr. Kripnitz."



SCIENCE

JANET & ISAAC ASIMOV

ESSAY 400–A WAY OF THINKING

Science is much more than a body of knowledge. It is a way of thinking.

— Carl Sagan

INTRODUCTORY NOTE:

ISAAC had written 399 science essays for Fantasy & Science Fiction *but was too ill to write the 400th. This troubled him deeply, so — because I was already writing one of his regular science columns — I suggested that we write the 400th essay together, recording his thoughts about science and science writing. Unfortunately, the essay was never written.*

Over two years have passed since Isaac died. Because I still want that 400th essay, I've finally put one together from our discussions and letters, plus an excerpt from his recently published autobiography.

My comments are marked by brackets.

This "essay" is not polished because the letters were not. Long ago, he wrote me about this: "My letters to you are first drafts; straight as it comes and completely unpolished; and I leave it to you to get past the maunderings and potterings and see my meaning. In fact, it is very wonderful to be able to leave it to you to do that — in full confidence and trust."

I leave it to Isaac's readers, in full confidence and trust.

[Janet, 1994. Today the economic state of the world forces governments and institutions to cut back on scientific research, which tends to be funded only if it promises practical, money-making results. Scientists are also hampered by increasing anti-science prejudice, growing as literacy decreases and fears proliferate. People want comforting answers and prom-

ises instead of truth. Carl Sagan recently summarized the problem by saying, "We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology."

Isaac was in complete agreement with Carl, and spent most of his life trying to help people understand science.]

[From a commencement speech] Science with all its faults has brought education and the arts to more people — a larger percentage — than has ever existed before science. In that respect it is science that is the great humanizer. And, if we are going to solve the problems that science has brought us, it will be done by science and in no other way.

[1966, telling me what he'd said in a letter to Carl Sagan] The brotherhood of science is one of the few ideals that transcend national boundaries and point the way to possible safety amid the dangers that threaten us.

[This is the quote from a published work — *I. Asimov: A Memoir* (which Isaac had called "Scenes of Life"), published by Doubleday in 1994] ...science *can't ever* explain everything and I can give you reasons for that decision...I believe that scientific knowledge has fractal properties; that no matter how much we learn, whatever is left, however small it may seem, is just as infinitely complex as the whole was to start with. That, I think, is the secret of the Universe.

[Helping people understand science had its difficulties. This is from a letter about an article he'd written for *Playboy* and which they wanted revised] ...I wrote a letter to *Playboy* suggesting that in my opinion they ought to do the article I sent them as it stands because I wasn't going to rewrite it into a silly sensational piece of the kind they were asking for. I explained that I had dedicated my life to educating the public and that science must not be viewed as a mysterious black box out of which came toys and goodies, for that way laymen would view scientists as a kind of lab-coated priesthood — and, eventually, fear and hate them. I couldn't connive at that view. I had to *explain* science and *Playboy* owed a duty to its public to have science explained and if most of their readership would rather not trouble their rusty heads, they could look at the Playmate of the Month. That's what she was there for. — Anyway, it was a very stub-

born and self-righteous letter and I haven't received any answer.

[In an article] I made fun of a reviewer who wanted less of a bang of statistics...and more of a moan of delight. I got a letter from a fan today who sympathized with me and who sent the following quotation from Alfred Noyes (you know, the *Highwayman* guy — which, by the way, turns out to be the favorite poem of Gene Roddenberry, and one he loves to recite thumpingly.) I never came across the quotation and I think it is beautiful and I want to pass it on to you —

> Fools have said
> That knowledge drives out wonder from the world;
> They'll say it still, though all the dust's ablaze
> With miracles at their feet.

[About a critical letter] ...from someone who says indignantly that if SF were scientifically accurate it wouldn't be SF and that if she wants an education she would go to school. I scowled formidably and sent back a postcard saying, "There is a difference between fiction and ignorance. If you want to be ignorant, that's your business." I work so hard to educate and here are people who would rather be stupid.

[I don't know if the following is Isaac's or something he read, but he said it with fervor] Uncertainty that comes from knowledge (knowing what you don't know) is different from uncertainty coming from ignorance.

[About a talk he gave at a college] I traced the history of science and man (science and *ordinary* man, not science and scholars) through three stages. First there was the stage where science meant *nothing* to the man in the streets and he turned to his various religious leaders for help in protecting him against the universe. The turning point came (according to my thesis) with Franklin's invention of the lightning rod — the first victory of science over a menace to man which had till then seemed unavertable and which had, indeed, been considered the direct artillery of Zeus, Thor, and Yahveh.

And, I added impressively, when the average man saw lightning rods rising over the steeples of the great cathedrals of Europe, he could see with his own eyes that the priests themselves trusted in science rather than in their own holiness, and the battle was over right there. In the last two centuries, religion has retreated

steadily before science. Also it led to 19th century Utopianism with regard to science. Science was Good and could solve everything.

The fact that science was also Bad, I traced to 1915 and the development of gas warfare, the first time that the average man could see, with the shock of sudden recognition, that a pure development of science could be outrageously bad and without mitigating good.

Since then we have lived in an ambivalent society where Science is both Good and Bad, where it poses us insuperable problems and dangers but where only it offers us the slightest hope of solution. I then looked into the future and pictured a possible ideal society in which work and risk were abolished and in which men slowly lost interest and declined in numbers while robots, who grew to be more and more manlike in appearance and ability, took over the work of the world.

Finally the last man was gone and only the robots, self-repairing and self-perpetuating, were left. And they puzzled over their dim memories of a Golden Age, as the centuries passed. Surely there had once been a race of demi-gods, who never had to work, who never suffered from disease, who did not die but who just fell asleep. How had all that been lost, and left their own race forever condemned to brutal labor?

One of the robots finally got an idea. "You see," he began, "there was this snake..."

And with that I ended the talk.

[Publishers had asked for a book on quasars but Isaac decided to write *The Universe: From Flat Earth to Quasar*]

What I did was to give a history of man's attempt to view the Universe as a whole, from Greek efforts to draw maps of a flat Earth, shaped like a saucer and 5000 miles across, to the entire observable Universe with a diameter of 26,000,000,000 light-years.

Gradually I extended the horizons: the Round Earth in Chapter 1; the Solar System in Chapter 2; the stars in Chapter 3; the Galaxy in Chapters 4 and 5; other galaxies in Chapter 6; questions of cosmogony (the origin and evolution of the Universe—which is the nub of the book) in Chapters 7 through 12. I then followed with a discussion of the various models and theories of the Universe that followed upon the realization that the galaxies receded from us, in Chapters 13 through 15. Finally in Chapters 16 and 17 I discussed the expansion of our knowledge of the Universe that arrived in

the mid-twentieth century through an understanding of radiation reaching us in forms other than visible light: neutrinos, cosmic rays, x-rays, and gamma rays.

The last two chapters dealt with radio astronomy, with colliding galaxies and exploding galaxies. And *finally* after 100,000 words, I brought up the quasars that I was asked to write the book about. But now, you see, instead of simply writing a journalistic account full of gee-whizzes which (like meringue) will feel and taste good but will leave you hungry, I have a good solid history of cosmology which the careful reader will find will stay with him. And the quasars will fit properly into the background so that he will see its full significance the moment they are mentioned.

Would you like to know what writing problems are like to someone who never suffers from a writing block? Well, I am working on a book on physical biochemistry (of sorts) which involves chapter upon chapter upon chapter dealing with thermodynamics to begin with. Now I am using the historical approach and historically the second law of thermodynamics was discovered before the first law, *but* it makes much more sense to discuss the first law first. How then can I discuss the first law first and the second law second without giving the impression that I am zigzagging in time (which I am). See?

[1966] I've just written my article called "Selenize or Die," which briefly states my thesis that it is important [for scientists] to start a Moon colony, for they will show us how to *really* construct a managed economy and it will be on them that the brunt of further space exploration will fall. The peroration is "Why spend billions to place a man on the moon? If we don't, we may lose the Earth. If we do, we may gain the Universe. You couldn't ask for better odds."

[About giving a talk to a small audience that seemed to possess "unsullied gravity"] ...since I don't prepare my talks I am guided entirely by audience reaction and not even consciously. I just automatically get more and more funny if the audience laughs...or less and less funny if the audience doesn't laugh. This time I got less and less funny and began an increasingly sober discussion of the possible usefulness of the Moon program, ending with the hope that the Moon colony would teach mankind how to live an ecologically sane existence, which brought me into the

problems of overpopulation and overpollution and I grew very intense indeed...I spoke rapidly and pulled no punches and everyone left shaken up and saying they wouldn't be able to sleep that night.

They should have laughed.

[About an interview with a reporter for a European magazine] She whipped out a recorder and asked if I'd mind and I said, "No." (What the heck, I'm not ashamed of anything I say.) Then I talked freely for two hours, giving her my feelings that...exploring space was something for all mankind and I hated to see it made a football for national rivalries, but perhaps that was the only way in this insane world of doing it at all; and I said that the Moon could never support enough men to make it a way of absorbing our population excess, and that the population explosion had to be solved by 2000 A.D. or else, and that we could not look for help from outer space but had to solve it by then right here on Earth; and that we had to stop polluting water and air and crowding other species recklessly off the face of the Earth; and that extending the life span to 200 years would be of dubious benefit since the population would explode that much faster and extending the life span of a small minority of worthwhile people would create such a problem of "who is to decide" that I dreaded the thought of it; and that in an automated world, boredom would be a painful epidemic disease, and that the worst punishment would be to take a criminal off the "work-lists" for the number of years required to fit the crime. — All like that there.

[The reporter] kept saying enthusiastically, "You're the first American who has said such things to me." It made me nervous...people can spout official statements...but I can say what I please; or at least I *will* say what I please.

[About the flap over whether or not flat-worms automatically became conditioned if they ate pieces of other, conditioned worms] ...I viewed this with severe suspicion (my "built-in doubter," you know) but finally decided that the only way it could happen was that RNA molecules (the key to memory) were incorporated whole into the cannibalistic worms since their organization was so low-key that they probably didn't require digestion when their food was so like themselves. To my delight, this turned out to be the most popular explanation by "real scientists." However, [a "very good scientist"] now insists that the work of the

worm-runners can't be confirmed; that flat-worms can't be conditioned. This gives me some sardonic amusement for, of course, John Campbell jumped on this at the very beginning, convinced that there was some explanation that would upset all of "orthodox science." (He is for anything far-out, not because he values the far-out, but because he wants to see the amateur — like himself — win over the professionals who wouldn't let him finish MIT.)

Also, have you read that the meteorite in which traces of life were discovered turns out to have been hoaxed a century ago? It is another example of the value of routine doubting. My thesis, in case you've forgotten, is not doubt-for-doubt's-sake, but doubt as a necessary barrier which the valid can overcome and the non-valid cannot. The more a finding seems to destroy the basis of the scientific structure, the higher the barrier of doubt. Of course one must remember that "doubt" is *not* synonymous with "refusal to listen."

I was on a two-hour radio show and discussed the origin of life...talked learnedly and rapidly about the development through chance of nucleic acid molecules, of evolution by natural selection, etc. etc. etc. In the second hour the listeners phoned in questions, and some of them were from Fundamentalists who were simply furious with me. They quoted from the Bible and denounced me as someone who would steal the beauty of the universe (as though the conceptions of evolution and the long history of the stars were not infinitely more beautiful than the story of a petulant God making and destroying a pint-sized basketball of a world.) One questioner, her voice shaking, would refer to me only as *that man* and addressed her questions (or rather her denunciations) only to the announcer. You would have been proud of me, though. I was calm and polite and smooth and in answering these people. I kept saying, "[Scientists] neither back the Bible nor refute it. The Bible doesn't concern us one way or the other." Of course that reduced them to gibbering fury and the announcer would then cut them off.

The trouble is these people have a comfortable little world of miracles and literal-word-of-the-Bible and associate only with others who live in the same world and go to a tiny, Fundamentalist church on Sunday and (like the green peas in the pod who thought the whole universe was green) honestly think that all the world thinks as they do. They don't read books on the scientific view, or

go to lectures, or attend courses — and then, they have the radio on and to their disbelief and horror, someone is spouting blasphemy at them and speaking of life originating by chance and mankind developing through the blind forces of natural selection and never mentioning God.

It's a wonder they don't break down at the mere fact that I am not being struck by lightning. Anyway, I think I brought some fresh air into the minds of a number who were not irrevocably wedded to ignorance. It was an interesting experience.

[1970] I have just received a very strange fan letter from a "Bible fundamentalist" who says, "After years of admiring you and your goodness in putting your knowledge into layman's terms so many of us could enjoy this great world of science with you, I am finally dropping these lines to tell you how much I appreciate what you have contributed to my faith in the literal word of God."

Dearest doctor — where have I gone wrong?

[Thirty years ago I wrote Isaac a letter he praised, so I'll include an excerpt:

...as you have pointed out in so many ways in your various articles...exposure to scientific method does alter the way one thinks, for the better. Even if one is disgustingly human in the primitive, fallible, unreasoning sense, nevertheless if one has once acquired the tool of scientific method—reasoning and experimenting and doubting and questioning—then at least it is there if one has the guts to use it. My last sentence amuses me. People — even I—say "disgustingly human" meaning all the primitive things. But scientific method is a human accomplishment and cannot be divorced from "being human."]

[In another letter I wrote to Isaac about an argument I'd had with a Fundamentalist relative:

...Some people will always believe any insane system if it happens to fit their needs enough, especially if their needs are very neurotic...but fewer people would be taken in if they got a thorough grounding in scientific principles in childhood. Every single child born in this age should have a rough idea of what scientific method is, so that their thinking runs along—at least vaguely — lines similar to those used by scientists when confronted with hypotheses, new data, new questions, etc. Not that scientists aren't prey to emotionalism and other forms of distorted thinking, but at least they have

the *tools* of thinking which they *can* use if they are not too anxious and frightened. My cousin doesn't have these tools and there is no use arguing with him, because he has no adequate means of appraising your reasoning or his own.]

[Isaac's response]...You and I are alike children of Thales, for he was the first known rationalist; the first to attempt to explain the universe without calling upon the supernatural; the first to believe, *by faith*, that the workings of the universe could be understood by reason. We share the same heritage, you and I, and our ancestors are men who withstood persecution and derision, who labored under difficulties and often without any sort of appreciation, who were rarely enriched and often impoverished by their work. In writing my biographies [of great scientists], I was in a sense writing the stories of our ancestors and was aware, as I was doing so, of a Mystic bond (well, I can think of no other word) that bound me to all those men of the past and to all the men of the time yet to come — those very, very few who are rationalists and who work at it.

[1963] A friend of mine commented idly that my book *The Human Brain* had made clear the meaning of EMF for the first time. As soon as I could get hold of the book myself I quickly looked up EMF in the index and turned to the page and read it, with great delight; feeling that I was sharing a learning experience.

How sad it is that for one reason or another (social, personal, philosophical. I don't know — *you're* the psychiatrist) learning usually becomes associated with pain, work, and boredom, so that as soon as school is over and enforced learning put to an end, the average person thankfully puts it all behind and proceeds to forget whatever he or she has learned, above the barest minimum of reading, writing, and third-grade arithmetic. (Really, for most people, there is no way of telling from their conversation or work that they have ever progressed beyond the third grade.) But I am not saying this to criticize; but rather to sympathize; for the loss is theirs, not mine.

It is not even *knowing* that really adds a joy to life, but the ability and eagerness to *learn*. For instance... [A friend's astronomy article] works out calculations that are of only minimal interest to me; but what does stay with me is the idea of Earth and Moon as two islands in the empty volume of a single body circling the Sun. It's just a way of looking at matters that never occurred to me

but which fascinates me now that it has been put into my mind. It adds to my picture of the universe; it gives me all the pleasure of new knowledge that a poem might give to one of literary bent or a sudden revelation might give to one of mystical bent. To learn is to broaden, to experience more, to snatch new aspects of life for yourself. To refuse to learn or to be relieved at not having to learn is to commit a form of suicide; in the long run, a more meaningful type of suicide than the mere ending of physical life.

I am now writing an *F&SF* article on...a subject I do not understand very well, but by the time I have written the article, I *will* understand it. In fact, I sometimes think my articles are a vast scheme of self-education. It works, too. There is nothing like writing an article on a subject for forcing yourself to think that subject through clearly.

All that is, has developed out of the random application of the laws of the universe, in my belief. I find the hypothesis of a directing intelligence to be more implausible than the hypothesis of a non-directing random process that just happens to be here at this point in time. It might have been somewhere else, but it happens to be here...

...We must distinguish between scientific knowledge and all knowledge. Scientific knowledge is only one sub-species of the genus. It is knowledge gained in a particular way. There is knowledge gained in other ways. For instance, a young man in love *knows* that his young woman is the most wonderful one in the world. He doesn't measure her in any way; he knows by a reaction in himself that is indescribable, let alone measurable.

[About a fan letter] He responds to my recent article in which I take off on mystical explanations of the universe. The fan points out that the Sun corresponds to the brain; the nine planets to the nine major openings in the body (two eyes, two ears, two nostrils, mouth, and, I presume, urethra and anus — the young man, apparently, having never looked closely at the feminine urethra and environs, completely missed a tenth opening, in the female at least), the asteroids (as an exploded planet) to the umbilicus, as an opening that once was but is no longer (Hmm, could the asteroids signify that tenth opening, broken up to indicate it is present in only one sex?). He also maintains that if we could count all the asteroids, comets, and smaller

bodies these would correspond exactly to the number of pores in the skin — the minor openings.

I am sending back a postcard saying, "Excellently reasoned! And as the umbilicus is in the middle of the body, so is the asteroid belt in the middle of the Solar System."

[1968] I have so far received two letters from people protesting my cavalier dismissal of Velikovsky, the first from a sociologist and the second from a philosopher, who protested that I was giving Velikovsky the dogmatic treatment that scientists were using to suppress him, and pointing out in his favor that he was being invited to speak at numerous colleges by heads of departments and was greeted with large and enthusiastic crowds.

In my answer, I said he couldn't have it both ways. If Velikovsky was constantly being invited to speak to large crowds at college campuses, then in what way was he being "suppressed"? And if large and enthusiastic crowds were the measure of truth then I wouldn't waste my time with Velikovsky, I would go straight to Billy Graham.

What I *didn't* say, because I thought it would be too cruel, was that the pro-Velikovsky clique was drawn almost entirely from non-scientist scholars like my friend the philosopher. There was the time when philosophers were the cream of scholar-hood and now the very word "philosopher" induces an almost involuntarily mocking smile which may not always be justified but which exists. The physical scientist is the new intellectual elite (also not necessarily justified, but a fact) and the philosopher, nose out of joint, is only too glad to jump on the bandwagon of a theory that seems to make out physical scientists to be a) stupidly wrong, and b) criminally persecuting.

[Dear Dr. Asimov, why on Earth did you bother to answer the letter writer who lectured you about your attitude toward Velikovsky? In the five minutes you typewrote your answer, stuffed it in an envelope, licked the stamp, and sealed it, you could have written lots of words for your new book. How many, at your rate of typing speed? You're the mathematician, not I. Figure it out. Be guilty.]

[In the margin of my letter Isaac wrote next to the "why"] Because I'm compulsive.

[About a review of one of his science books] I sat down and wrote a perfectly furious letter...I pointed

out that facts were facts and that I was shocked to know that he favored altering facts to fit theory and that this worried me because in the same issue *he* had an article favoring the widespread use of pesticides and I wasn't sure it was safe to listen to him...

After I wrote the letter, and addressed an airmail envelope and sealed the envelope, I found my fury evaporating. I reread the review and found it was stupid but not as evil as I had thought. He had even used the adjective "interesting" at one point so that the review was not solidly bad. So now I have to nerve myself to tear up an envelope with a perfectly good stamp on it.

P.S. I've just torn it up.

[He loved Benjamin Franklin]... Just the other day I learned something new about him. During the American Revolution, Captain Cook was engaged in his phenomenal sweeps across the Pacific Ocean. He was the first of the great modern scientific explorers, searching not for gold, trade or colonies but for knowledge. In those days, American privateers were scouring the seas looking for British craft to sink out of a little bit of patriotism and a whole lot of love of loot. Captain Cook, however, went untouched and undisturbed, officially protected against harm by the American revolutionaries, at the advice and insistence of Benjamin Franklin.

Franklin quite well realized that the search for knowledge (of the universe by scientists, of man's senses and emotions by writers and artists, of man's ethics and behavior by psychologists, philosophers and — ugh — theologians) was mankind's highest purpose in life and was what made man man and not merely another animal. Most of all he realized, and made the American government realize, that it stood even higher than purely national interest.

We're living in a time when science has made "purely national interest" completely obsolete, only not enough of us realize it. Men like Kennedy and Khrushchev realize that "purely national interest" is a long name for suicide and are trying (with the greatest possible difficulty and reluctance) to place the good of humanity first. Then there is another group who also recognize the obsolescence of ordinary nations but wish to try another division on the basis of color, with Communist China, the Union of South Africa, the American Southland all on the side of the devils.

[About *Dr. Strangelove*] I am by

no means sympathetic with the view that one must never make fun (let alone savage fun) of scientists. Much as I admire, love, and revere science and scientists, I recognize perfectly well that both science and scientists — like *all* subjects — are fair targets for the satirist. Indeed, to exempt scientists from satire, or even from malicious probing, would be extremely dangerous for science. To make a religion out of it would be to enthrone its worst aspects — its authoritarianism, its unapproachability, etc.

And in particular, I myself realize the danger that science may become—willingly—the handmaiden of nationalism and the great danger to humanity. There *are* scientists who recognize their first duty to an arbitrary segment of the human race, rather than to mankind generally; and there *are* scientists who would put their own pride in their own creations, or theories, or their own wounded self-love above the best interests of mankind. Yes, I am thinking of Teller, of course, and I wonder if Peter Sellers is thinking of him as well as of Werner von Braun, for instance.

[In another letter] The thing that gets me is that people are ready to consider scientists evil for their part in the bomb, but scientists are those who have rebelled against the bomb (not all of them, of course) and fought against it. It was the politicians that actually made the decision to use it, and the military that used it — and where is a single politician or military man who has ever regretted publicly his part in the atomic bomb and its use? It is my theory that the type of mind which is today drawn to science, which in ancient times was drawn to philosophy, in medieval times to theology — is not only the best mind but the good-est mind. (Which, of course, does not mean that there are not rats in the ranks of science.)

[About an old sf movie] The Earth *can't* leave its orbit and swirl toward the sun as a result of anything, anything, anything that happens on the Earth. An external force must be applied. The Earth can be blown into tiny pieces as a result of actions on the Earth and some of the pieces may hurtle toward the sun, but then an equivalent mass must hurtle in the opposite direction and the center of gravity of all the pieces will continue to move majestically about the sun just as it is doing. Damn it, not to know this (and nobody in the movie capital does) is to be pre-Galilean. It is equivalent in the artistic world of

saying that Mozart wrote *Götterdämmerung.* And it's no use saying, "Oh, well, the stupid jerks who watch the picture won't know the difference and wouldn't care if they did." In this present world, scientific illiteracy is a sin and anyone who encourages the spread of scientific illiteracy is a criminal.

...A lot of good it does us to try to teach legitimate physics in schools, when the movies do things that prove they never heard of the conservation of angular momentum.

[About vandalism and terrorism] The whole world is being burned down or torn up or broken to pieces and people don't care. I have reached the point where I can almost hope that the death rate goes up quickly, *very* quickly, with maximum damage to humanity and minimum damage to the rest of the animal kingdom and the inanimate environment so that the old planet has a chance to recover. I am becoming misanthropic. Individual human beings are becoming monsters incapable of any kind of motive except that of grabbing what they can from the universal wreckage.

[After a discussion in 1961] I have always been quite impatient with philosophy and philosophers, going no further in my thoughts than to reach certain unpleasant stereotypes which consisted, chiefly, of having them *far* inferior to scientists. The necessity of philosophy, the fact that science is based on a philosophy, and can only discuss its results in terms of philosophy — that I myself am consistently philosophical in my writing — all these things were at once so obvious and apparent that I am dreadfully ashamed at...having had to have it pointed out...

[But we did sometimes argue in letters and he usually won] You must not use the phrase "19th-century mechanists" as though it were a dirty word. The 19th-century mechanists were a heck of a lot closer to the mark than were their competitors, the vitalists, the theologians, and the mystics. By a "mechanist" I mean someone who thinks that the behavior of the universe can be interpreted through a series of general statements which we can call "laws of nature." That the universe and its component parts always behave so as to agree with the laws of nature and cannot disobey. This negates any thought of "free will" or a "directing intelligence" or a "god" if you want me to be blunt. It also implies that man, as part of the universe, lacks free will and cannot disobey the laws of na-

ture. In short, the universe has characteristics in common with those we recognize in a machine.

This view of matters was emotionally offensive to many who felt bound and determined to consider themselves as more than machines, as equipped with free will and souls and all the rest. Consequently there was vast relief among many philosophers when it turned out that the 19th-century mechanists didn't know as much as they thought they did. (Nobody does, and the odd part is that 19th-century mechanists were a lot less arrogant in this respect than their opponents...)

The great addition that had to be made can be summed up in the one word "probability." The gas laws weren't as absolute as they seemed, once they were interpreted as the result of random motion of particles. They fuzzed out into probability. The uncertainty principle fuzzed everything out into probability.

This didn't mean the universe was not a machine. It simply meant that we didn't know as much about machines as we thought we did. The Universe is governed by uncertainty in that we can't say yes or no, but so are all machines. We can set up mathematical expressions that precisely express the probabilities. We can't stop the fuzziness from being fuzzy, but we can describe the nature of the fuzziness. And the Universe is *still* a machine; we just know more about machines,that's all. So I'm a 20th-century mechanist—and a very thoroughgoing one—and I will not admit that there is any reason to suppose that everything in the universe cannot be satisfactorily explained on the basis of material things (with energy and matter both considered material).

In other words, in order for arrangement, order, interrelationship and all such abstractions to have meaning, there must be order and arrangement of *certain material objects.* And you will never truly understand order and arrangement until you know what it is you are ordering and arranging.

For instance, it is quite possible to study symptoms and cures of diseases without knowing anything about the cause of the disease. Great successes can be achieved even. Vaccination and quinine were introduced when only superficial knowledge existed concerning smallpox and malaria. However, it was only after the germ theory of disease was introduced that medicine became more than empirical guesswork. Which was more important, good doctor? Vaccination or germ theory? And, if it were possible by skimping on re-

search into vaccination to have discovered the germ theory twenty years sooner, would that not have been beneficial in the long run?

The greatest discovery in biology was the theory of evolution which was essentially an order-and-arrangement discovery, yet it could not have been made unless and until the concept of species was introduced.

To be sure,life is more complex than the DNA molecule, just as matter is more complex than the atom, since matter includes all the interatomic forces. However, until the atom is understood, the interatomic forces will not be. The study of life will remain fuzzy and mystical until we know exactly what the fundamental basis of life is. *Then* we can turn to the order and arrangement that makes up all the higher subtlety of life and *finally* understand them. And if we skimp on the order and arrangement now in order to more quickly understand what we are ordering and arranging, we will get there faster in the long run.

Or, to give another example, consider that the great advances in chemistry were made in three stages. First, after the concept of element had been introduced; second, after the concept of the atom had been introduced; and thirdly, after the concept of the electronically charged subatomic particle had been introduced. In no case do we say that sulfuric acid is *really* a mixture of elements (it isn't) or *merely* a conglomeration of atoms (it isn't) or *only* a mass of electrons and protons (it isn't). It is all these things plus organization, yes. But every time we found out a little more about what was being organized, we found out a great deal more about the organization.

Now the traditional biologists can continue what they are doing, but all the problems they strive so painstakingly to solve will fall into place without difficulty when the DNA boys finally solve their molecular biology. And anything we can do to help along the DNA boys is for the benefit of the traditional biologists as well.

[After a similar argument, I agreed with him and he answered:] Thank you for trying to understand my commitment to the battle of Reason against Chaos, even when I show the battle at its worst by dashing suddenly at windmills. And I shall try, with all my heart, to understand your commitment to the battle of the Heart against all the Blindness and Indifference of the world...if at times we veer apart in the comparative stress we lay upon Heart and Mind, I know we will find our way back to

the common battle of Good (of Heart and Mind) against the Evil (of Indifference and Ignorance).

In [the letter column of a reputable science journal] an argument rages between the traditionalists of biology and the molecular biologists. The traditionalists insist they are not vitalists and point out that the molecular biologists are biochemists by training and know virtually nothing of biology. The molecular biologists insist that the traditionalists *are* vitalists and stubbornly insist on the molecular biological road to ultimate biological truth.

At first blush, I am heart and soul with the molecular biologist, and yet as I think of it in the light of what I have learned [during our arguments], I find both sides incomplete. It is certainly truth that the average molecular biologist is a chemist rather than a biologist, but surely this gives the traditional biologist a wonderful chance. Let him learn molecular biology and adapt it to his own knowledge of traditional biology. Let the two merge; for all learning is one, and though there may be enemies among scholars there can be no enmity among scholarship.

As an example from history, when Pasteur (a chemist) advanced the germ theory of disease, the traditional doctors may well have pointed out that Pasteur was a microscopist who could see answers only in the microscopic world and that he knew nothing about medicine itself. True! But Robert Koch took Pasteur's bacteriological work and applied it to medicine in systematic fashion and revolutionized the art.

I was on local radio tonight and people from the listening audience called in, all of them saying how great I was. Still, one of the guys, after explaining that he had read me for years, went on to insist on giving his views on flying saucers which were as kooky as possible. We were going to destroy the sun and cause a disruption in the fabric of time and that was what the people in the flying saucers were trying to prevent and he knew that I knew this perfectly well but might be afraid to say so. I pushed him off as gently as I could but, my goodness, if people think that *this* is what reading me for years brings people to, they may burn my books.

[He had complained about the price of fame, so I reminded him of what Henry Fielding said: "Do thou teach me not only to foresee but to enjoy; nay, even to feed on future praise. Comfort me by a solemn assurance that when the little parlour

in which I sit at this instant shall be reduced to a worse furnished box, I shall be read with honour by those who never knew nor saw me, and whom I shall neither know nor see." Isaac replied:]

How minds can meet and agree across the centuries! Isn't it much greater to be Homo sapiens than to be part of any artificial subclass thereof?

[About a fan's letter praising one of his books on science] I am absurdly gratified whenever someone tells me that the book has "reawakened a forgotten joy in learning" because that is what I try to do; that is my mission; only how do I go about saying so without sounding priggish and mawkish? We live in a society in which it is impermissible to be idealistic; where to wish to do good and to help one's fellow-man in any way is so laughed out of court that those who most wish to do so (for the very selfish reason that it makes them feel good and gives meaning to their life) must clothe their actions in selfish terminology as I have just done and must live constantly in fear of being accused of hypocrisy or worse...Oh, Dr. J, it would be so much better to give than to receive, if it were two different actions; if it weren't that only by giving can one receive, and only by receiving that one can give. I want to give in so many ways, on so many levels, to so many recipients—love and joy and knowledge—and in so doing I find love and joy and knowledge, for in the most concrete of the three, knowledge, it is absolute truth that I have never written a book that didn't teach me far more than it taught any reader.